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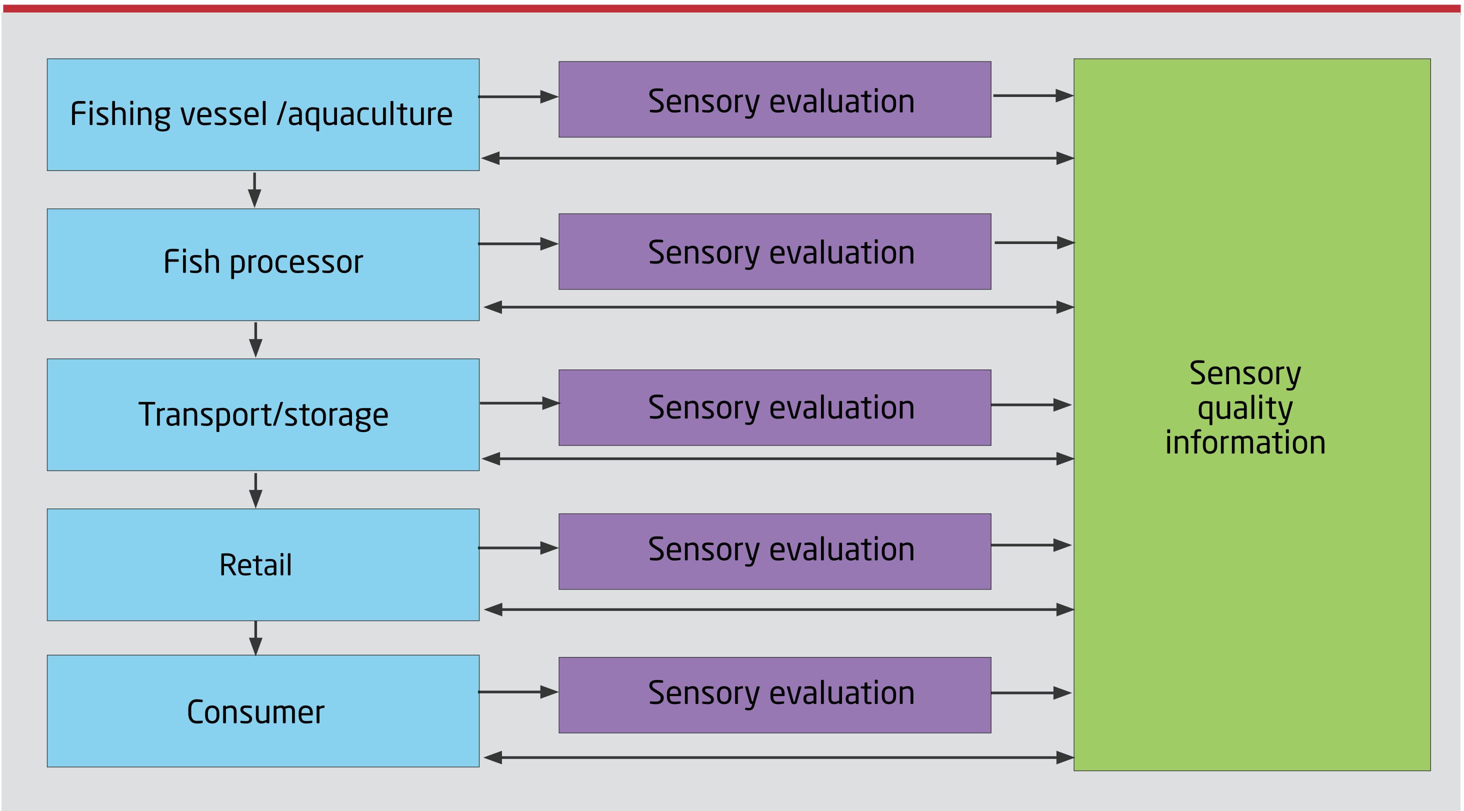

Ditte M.B. Green-Petersen
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Sensory Quality of Seafood-
in the chain from catch to consumption

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Preface

This thesis is submitted as a requirement for obtaining the Ph.D. degree at the Technical University of Denmark (DTU). The study was carried out at the Division of Seafood Research at DTU National Food Institute in Lyngby, Denmark, during the period from November 2004 until March 2010.

The work was carried out within the integrated research project SEAFOODplus, contract No. FOOD-CT-2004-506359. Funding from the European Union is gratefully acknowledged. Funding from FOOD Ph.D. school is also gratefully acknowledged.

I would like to thank my supervisors, senior research scientist Grethe Hyldig, senior research scientist Bo Jørgensen, and head of section Jette Nielsen for their support, constructive advice and guidance during the project.

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I would also like to thank my colleagues for providing an inspiring and friendly working environment. Carsten Østerberg, Chiara Foschi, Claus Reesbøll, Heidi Olander Petersen, Hugo Ladefod, Inge Holmberg, Thi Thu Trang Vu, Jeannette Unger Møller, Rie Sørensen and Ulrik Cold are especially thanked for their practical and technical help during the experimental work. Also, I would like to thank the sensory panel and the consumers for participating. I would like to thank Søren Tørper Christensen for providing me with literature. Sally Clink, Chiara Foschi and Maria Randrup are acknowledged for their valuable advice during preparation of the papers.
Finally, I would like to thank my family and friends for help and support. A special thanks to my husband, Allan, for his support and to my sons, Jakob and Stig for smiles and laughter.

Ditte Green-Petersen

March 2010

Summary

Sensory quality can be defined as quality which can be assessed by the human senses, and sensory quality has a key influence on how consumers perceive the quality of a product. However sensory quality of seafood products is complex, since it is influenced by many different factors. Some factors are connected to when the fish still is alive, but there are also factors related to the treatment in the seafood processing chain, which begins when the fish is caught wild or in aquaculture and ends when the fish is consumed. The overall objective of this work was to obtain knowledge and develop tools which can be used to improve the sensory quality of seafood products.

The results have shown a substantial variation in the sensory characteristics of the salmon product available on the Danish market. One factor which was especially found to influence the sensory quality was frozen storage time. Additionally a consumer study was carried out on salmon products which differed in relation to salmon species, origin, storage method and time. The consumer study included consumers from Denmark, Iceland, Ireland and the Netherlands. The salmon samples were also analysed in an objective sensory profiling performed with a trained sensory panel. The results showed that objective sensory quality influences the consumer preference of salmon products. For some of the products differences were found between the consumers from the participating countries. These differences were mainly between consumers from Iceland and Denmark. By using clustering analysis it was possible to find clusters of consumers that preferred different storage methods.

The consumer study included an open-end question were consumers could describe their preferences for each of the products and the answers to this question were analysed. A high correlation between the consumer descriptions and the objective sensory profile was ascertained. Furthermore additional information about samples was obtained by analysing consumers' descriptions. The results therefore show that it is possible to analyse consumers' comments to open-end questions, and obtain valuable information about seafood products.

An experiment was carried out on Rainbow trout to study how much variation there is in the sensory quality of fish from the same aquaculture production batch. The results showed differences in sensory characteristics between individual and groups of Rainbow trout collected at

different times during a production day. This finding must be taken under critical consideration in industrial processing of fish and also in relation to scientific studies. Generally the variation will increase the number of samples needed to make valid conclusions. Additionally all assessors used in sensory evaluations should get samples from the same fish if possible, particularly during training, but also in the main experiment.

The ultimate tool for measuring sensory quality in the seafood processing chain is sensory methods. Although it is well known that the partners in the seafood processing chain do use sensory evaluation, the evaluations are generally not performed in the most optimal way. A considerable problem is that there is generally no communication of demands to sensory quality and results from sensory evaluations between the different partners in the chain. Communication of sensory quality in the seafood production chain would be beneficial for the partner performing a particular sensory evaluation, but also partners earlier and later in the processing chain. Therefore a Seafood Sensory Quality Model (SSQM), which can be used for communicating sensory quality between the partners in seafood production chain, is suggested. The SSQM makes it possible to share the understanding of the sensory quality in the chain. Not only results from sensory evaluation and demands to sensory quality can be included in the model, but also other information that have an influence on the sensory quality. Using the SSQM in the seafood processing chain would increase the general sensory quality of seafood products produced, which again could increase the consumers' consumption of seafood.

Valuable knowledge has been obtained about the sensory quality of seafood and a model for establishing communication of sensory quality in the seafood processing chain has been suggested. This knowledge and the model can be used by partners in the seafood processing chain to optimize the sensory quality of seafood products. Additionally, important knowledge has been obtained in relation to how to design and carry out sensory studies of seafood products.

Sammendrag (Summary in Danish)

Sensorisk kvalitet kan defineres som den kvalitet der kan måles med de menneskelige sanser. Den sensoriske kvalitet har indflydelse på hvordan forbrugeren opfatter kvaliteten af et produkt. Imidlertid er den sensoriske kvalitet af fiskeprodukter kompleks, da den sensoriske kvalitet bliver påvirket af mange forskellige faktorer. Nogle af disse faktorer vedrører den levende fisk mens andre er relateret til behandling i fiskeforarbejdningskæden, som begynder når fisken bliver fanget i naturen eller i et dampbrug og ender når fisken bliver spist. Formål med projektet var at skaffe viden og udvikle værktøjer som kan bruges til at forbedre den sensoriske kvalitet af fiskeprodukter.

Resultaterne har vist at der er en betydelig variation i de sensorisk egenskaber af lakse produkter tilgængelige på det danske marked. En faktor som havde væsentlig indflydelse på de sensoriske egenskaber var fryselagrings tiden. Endvidere blev der udført en forbrugertest af lakseprodukter som varierede i relation til art, oprindelse, lagringsmetode og lagrings tid. I forbruger testen deltog der forbrugere fra Danmark, Island, Irland og Holland. Produkterne blev ligeledes analyseret i en objektiv sensorisk profilering med et trænet sensorisk panel. Resultaterne viste at objektiv sensorisk kvalitet havde indflydelse på forbrugernes præferencer. For nogen af produkterne var der forskelle mellem forbrugernes præferencer i de forskellige lande. Der var primært forskelle mellem forbrugernes præferencer i Island og Danmark. Ved at bruge cluster analyse var det muligt at identificere grupper af forbrugere, som havde forskellige præference med hensyn til lagring metode.

Forbrugertesten inkluderede et spørgsmål hvor forbrugerne med deres egne ord kunne forklare deres præference for hvert produkt og svarene på dette spørgsmål blev analyseret. Der blev i høj grad fundet overensstemmelse mellem forbrugernes beskrivelser og resultaterne fra den objektive sensoriske profilering. Desuden resulterede analysen af forbrugernes beskrivelser i yderligere information vedrørende prøvernes sensoriske egenskaber. Resultaterne viser at det er muligt at analysere forbrugernes beskrivelser af fiskeprodukter og opnå værdifuld information om fiskeprodukterne.

Et andet forsøg blev udført på regnbueørred for at undersøge hvor meget variation der er i den sensoriske kvalitet af fisk fra det samme produktions batch fra et dampbrug. Resultaterne viste at

der i flere tilfælde var forskelle i de sensoriske egenskaber mellem de enkelte regnbueørreder og mellem grupper af regnbueørred, som var udtaget på forskellige tidspunkter i løbet af en produktionsdag. Dette resultat har betydning både i forbindelse med produktion af fiskeprodukter men også i forbindelse med videnskabelige studier. Generelt vil variation betyde at antallet af prøver der bør udtages øges for at der kan opnås pålidelige konklusioner. Endvidere bør alle dommere i sensoriske bedømmelser hvis det er muligt bedømme prøver fra den samme fisk, specielt under træning men også ved bedømmelserne.

Det ultimative værktøj til at måle sensorisk kvalitet i fiskeforarbejdningskæden er sensoriske metoder. Sensoriske metoder bliver da også brugt af de forskellige partnere i fiskeforarbejdningskæden, men generelt ikke på den mest optimale måde. Et betydeligt problem i denne sammenhæng er at der oftest ikke er nogen kommunikation af kravene til den sensoriske kvalitet og resultater fra sensorisk bedømmelser imellem de forskellige partnere i kæden. Kommunikation af sensorisk kvalitet i kæden vil være gavnlige for den partner der fortager en sensorisk bedømmelse, men også for partnere placeret tidligere eller senere i kæden. Derfor er der forslået en sensorisk kvalitets model som kan bruges til at kommunikere sensorisk kvalitet mellem de forskellige partnere i kæden. Modellen gør det muligt for partnerne i kæden at få en større forståelse af den sensoriske kvalitet i kæden. Ikke kun resultater fra sensoriske målinger og krav til den sensoriske kvalitet kan anvendes i modellen, men også anden information som har betydning for den sensoriske kvalitet. Anvendelse af modellen kan generelt øge den sensoriske kvalitet af fiskeprodukter, hvilket kan medføre at forbrugerne øger deres indtag af fiskeprodukter.

Værdifuld viden om sensorisk kvalitet af fiskeprodukter er opnået, og en model til at etablere kommunikation af sensorisk kvalitet i fiskeforarbejdningskæden er blevet forslået. Denne viden og modellen kan bruges af partnerne i kæden til at optimerer den sensoriske kvalitet af fiskeprodukter. Desuden er der opnået vigtig viden i relation til at designe og udførelse af sensoriske forsøg på fiskeprodukter.

Abbreviations

A	Appearance
F	Flavour
MA	Modified Atmosphere
O	Odour
PC	Principal Component
PCA	Principal Component Analysis
PLSR	Partial Least Squares Regression
QI	Quality Index
QIM	Quality Index Method
RMSEP	Root Mean Square Error of Prediction
S/N	Signal to Noise ratio
SSQM	Seafood Sensory Quality Model
T	Texture

Species and common names of fish species used in the experiments

Salmo salar	Atlantic salmon
Oncorhynchus keta	Chum salmon
Oncorhychus kisutch	Coho salmon
Oncorhychus mykiss	Rainbow trout

List of papers

I Sensory profiles of the most common salmon products on the Danish market.

Ditte Green-Petersen, Jette Nielsen and Grethe Hyldig.

Journal of Sensory Studies 21, 415-427, 2006.

II Consumer preference and description of salmon in four Northern Atlantic countries and association with sensory characteristics.

Ditte Green-Petersen, Grethe Hyldig, Kolbrun Sveinsdóttir, Rian Schelvis and Emilía Martinsdóttir.

Journal of Aquatic Food Product Technology 18, 223-244, 2009.

III Variation in sensory profile between individual Rainbow trout *(Oncorhynchus mykiss)* from the same production batch.

Ditte Green-Petersen and Grethe Hyldig.

Journal of Food Science 75(9), S499-S505, 2010

IV A model for communication of sensory quality in the seafood processing chain.
Ditte Green-Petersen, Jette Nielsen and Grethe Hyldig.

Critical Reviews in Food Science and Nutrition. *In printing*

Other papers and contributions made during the Ph.D. study, but not included in the thesis:

Ditte Green-Petersen, Chiara Foschi and Grethe Hyldig. 2010. Development of Quality Index Method schemes for Rainbow trout (*Oncorhynccus mykiss*) farmed in fresh and saltwater. Journal of Aquatic Food Product Technology. *Under preparation*

Hanne Løje, Ditte Green-Petersen, Jette Nielsen, Bo Jørgensen and Kristina N. Jensen. 2007. Water distribution in smoked salmon. Journal of the Science of Food and Agriculture 87(2), 12-217.

Kolbrun Sveinsdóttir, Emilía Martinsdóttir, Ditte Green-Petersen, Grethe Hyldig, Rian Schelvis and Conor Delahunty. 2009. Sensory characteristics of different cod products related to consumer preferences and attitudes. Food Quality and Preference 20, 120-132.

Martinsdóttir, E., Sveinsdóttir, K., Green-Petersen, D., Schelvis, R. and Hyldig, G. 2008. Improved eating quality of seafood: the link between sensory characteristics, consumer liking and attitudes. In: Improving seafood products for the consumer. Børresen T. (Ed.), Woodhead Publishing Limited, Cambridge, UK. pp. 40-62.

Contents

Introduction

The sensory quality of a product can be defined as the quality that can be assessed by the human senses (Lawless and Heymann, 1998). Therefore sensory quality has a key influence on how consumers perceive the quality of a product and on consumers' preferences.

It is known that there can be considerable variation in the chemical composition of individual fish from the same aquaculture production batch (Løje, 2007; Schlechtriem et al. 2007). Additionally Robb et al. (2002) have shown that lipid content can affect the sensory characteristics of Atlantic Salmon (*Salmo salar*). However the literature on the variation of sensory characteristics of fish treated in the same way is limited. Considerable variation in the sensory characteristics of fish from the same production batch can have a significant influence, both in relation to scientific studies and in industrial production.

The sensory quality of seafood products is complex, since it is affected by many different factors. These include factors from when the fish still is alive, but also factors related to the treatment in the seafood processing chain, which begins when the fish is caught wild or in aquaculture and ends when the fish is consumed. Consequently the sensory quality perceived by the consumers in the final step of the seafood processing chain is a result of all these factors. The ultimate tool for measuring sensory quality is sensory methods. It is well known that the seafood industry uses sensory evaluations, however the evaluations are generally not performed optimally (Martinsdóttir et al., 2008). One of the essential problems in the use of sensory evaluations in the seafood processing chain is that demands to sensory quality and results from the sensory evaluations performed in the chain are not communicated to the different partners in the chain. Optimizing the use of sensory evaluation in the seafood processing chain could lead to a general increase in the sensory quality of the finial products and this could possibly increase consumer satisfaction and consumption of seafood.

The overall objective of this work is to obtain knowledge and develop tools which can be used to improve the sensory quality of seafood products by the seafood processing industry. In order to do this, studies were set up to answer following questions:

- What is the sensory quality of the existing products on the market?
- What is the connection between objective sensory analyses and consumer preferences?
- Are consumer descriptions of fish products comparable with descriptions obtained with objective sensory methods?
- How much variation is there in the sensory quality of fish from the same aquaculture product batch?
- How can communication of demands to sensory quality and results from sensory evaluations be established in the seafood processing chain?

Outline of thesis

This thesis is divided into four main chapters. Chapter 1 gives an introduction to the background for the work presented in this thesis. Chapter 2 describes the design of the experiments and the main methods used in the experiments and the data analyses. Chapter 3 presents the main results and discussion from the attached papers together with unpublished results. Chapter 4 presents the conclusions and the perspectives.

Chapter 1: Background

This chapter gives an introduction to the background for the thesis. Section 1.1 introduces the concept of sensory quality of seafood. This including a discussion of the vital role of sensory quality in relation to consumers (Section 1.1.1), an introduction to which factors influence the sensory quality of seafood (Section 1.1.2) and an introduction to management and control of sensory quality in the seafood processing chain (Section 1.1.3). The subject of Section 1.2 is salmon and trout, since the experiments discussed in this thesis are performed on either salmon or trout. The section also gives a short introduction to the significance of salmon and trout in relation to production and consumer consumption (Section 1.2.1), and a description of factors which influence the sensory characteristics of salmon and trout (Section 1.2.2).

1.1 Sensory quality of seafood

One general definition of quality is that it is the degree to which products meet certain needs under specified conditions. This means that the definition depends on the particular context in which it is applied. Quality is also a multidimensional concept since generally many different parameters affect a product's quality (Bremner, 2000). Therefore many factors influence the perception of food quality as described in the Total Food Quality Model, introduced by Grunert et al. (1996).

Similarly, the quality of seafood and seafood products is complex, and can be defined in many ways (Bisogni et al., 1986). The definition can be related to species, biological parameters, season, origin, technological parameters, nutritional value, microbiological, biochemical and physiochemical characteristics. When discussing the quality of seafood products, it is however also important to remember the sensory quality. Sensory quality of a product can be defined as the quality which can be assessed by the human senses (Lawless and Heymann, 1998).

1.1.1 The importance of sensory quality in relation to consumers

Consumption of fish is related to some positive effects on consumer health. One of the important positive health effects is reducing the risk for coronary heart diseases (WHO, 2003), but other positive effects of a high consumption of fish are known (Calder, 2006; Hibbeln, et al. 2007;

Thorsdottir et al. 2004). These health effects are often related to the general high content of omega-3 polyunsaturated fatty acids in fish. However fish also contain other important nutritional components, including proteins with a high biological value together with minerals and vitamins (FAO, 2009; Danish Ministry of Food, Agriculture and Fisheries, 2008). However, consumption of fish has also linked to health risks connected to environmental contamination with, for instance, mercury and dioxin. Nevertheless studies have shown that the health risk is acceptable when compares to the positive health affects (Dewailly, et al. 2007; Domingo, 2007; Sidhu, 2003). Therefore it is recommended to eat two portions of fish a week (Food Standards Agency, 2007; WHO, 2003; Danish Ministry of Food, Agriculture and Fisheries, 2008), but generally consumers in Denmark, as well as many other countries, eat less fish than recommended (Scientific Advisory Committee on Nutrition, 2004; Brunsø, 2003; Welch, et al. 2002).

The consumers generally know that eating fish is healthy and this is a significant factor for motivating consumers to eat fish, but several other factors also affect consumers' consumption (Bredahl and Grunert, 1997; Brunsø, 2003; Brunsø et al., 2009; Grunert et al. 1995; Myrland et al., 2000; Nauman, et al 1995; Olsen, 1998; Olsen, 2003; Olsen, 2004, Olsen et al., 2007; Pieniak, 2008; Pieniak et al., 2008; Trondsen et al., 2004;Verbeke and Vackier, 2005; Verbeke et al., 2007). One important factor in this connection is the sensory quality. Verbeke and Vackier (2005) found that sensory liking of fish was the most important factor in relation to intended fish consumption. This result is supported by results from Bredahl and Grunert (1997). Also Brunsø et al. (2009) found that taste together with health were the most important motivational factors related to eating fish. Bisogni et al. (1986) performed a survey in USA and found that freshness, quality and flavour were important factors for between 95 to 98% of the consumers when considering purchasing fresh fish. Furthermore it has been shown in a study from Norway (Aas, 2001) that the fishmongers believe that consumers consider quality more important than variety and price. Another study from Norway (Olsen, 1998) additionally showed that there are considerable differences in what consumers consider as optimal quality of fish and the quality of the fish that they can buy in the shops. Furthermore this study showed that lack of access to good quality fish can lead to lower consumption of fish. This finding is supported by the results of Trodsen et al. (2003).

Consequently a higher general sensory quality of fish products available for the consumers might induce a higher consumption of fish. Furthermore it might also be possible to induce a higher consumption of fish by getting more knowledge about how differences in sensory quality influence consumers' preference for fish products, and using this knowledge to guide the industry to design products with high consumer preferences.

1.1.2 Factors influencing the sensory quality of seafood

Many different factors affect the sensory quality of seafood products (Figure 1.1). Some factors are related to the living fish, but the treatment of the fish in the seafood production chain also influences the sensory quality. The seafood production chain includes all the steps from catch/slaughtering to consumption.

The factors of relevance for the sensory quality of seafood related to living fish include species (Cardello et al., 1982; Chambers and Robel, 1993; Hamilton and Bennett, 1983; Prell and Sawyer, 1988), age (Johansson et al. 2000; Nielsen et al. 2005), sexual maturation (Bilinski et al., 1984; Reid and Durance, 1992), genetics (Norris and Cunningham, 2004), season (Nielsen et al., 2005; Mørkøre and Rørvik, 2001; Roth et al., 2005), sex (Norris and Cunningham 2004), whether the fish is farmed or wild and other growing conditions. These conditions include e.g. water quality (Farmer et al., 2000), feed (Einen and Skrede, 1998; Thomassen and Røsjø, 1989), and presence of disease and parasites.

As already mentioned, the handling in the seafood processing chain can also influence the sensory quality. Which steps are included in the chain depend on the final product, but steps can be include; catching, slaughtering, cutting, further processing, transport and storage. The different steps take place in different locations such as fishing vessels, aquaculture ponds and pens, slaughterhouses, different means of transport, processing industry, fish shops, supermarkets, catering businesses and consumers' homes (Hyldig et al. 2007; Hyldig 2007).

In all the steps in the chain, time and temperature is very important for the sensory quality, because the loss of freshness is a major contributor to the sensory quality (Nielsen et al., 1997; Olafsdottir et al., 1997; Peavey et al., 1994). How fast the freshness declines depends on the temperature, but also on other factors like packaging atmospheres (Hong et al., 1996). Sensory quality can also be reduced by microbial contamination or by physical damage. Other factors like packing method, quality of the gutting, filleting or other types of ennobling also influence the sensory quality of the end product (Hyldig et al., 2007).

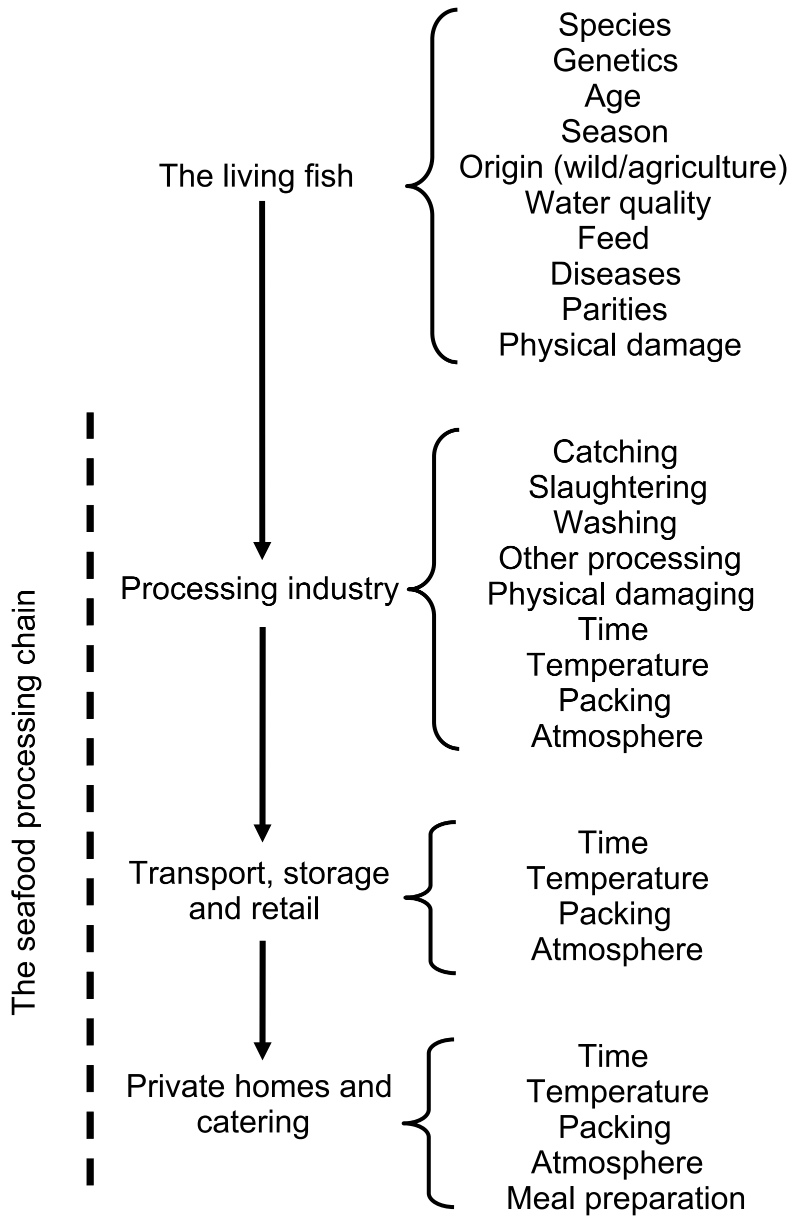

Figure 1.1: Overview of different factors, which can affect the sensory quality in the fish processing chain.

It is known that there can be considerable variation in the chemical composition, including the lipid content, of individual fish which have been treated the same way. For instance Katikou et al. (2001) found that lipid content in farmed Atlantic Salmon (*Salmo salar*) from the same production batch differed from 7 to 24%. Løje (2007) found variation between 4 and 11% in lipid content in fillets from Rainbow trout (*Oncorhynchus mykiss*). The chemical composition of fish can affect the sensory characteristics of the fish. Robb et al. (2002) found that the lipid content of smoked and cooked Atlantic Salmon (*Salmo salar*) has a significant effect on both texture and flavour. Rørå et al. (1998) have additionally found that the lipid content of smoked Atlantic salmon (*Salmo salar*) affected the colour. Possibilities to find variations in sensory characteristics of individual fish from the same aquaculture production batch can therefore be expected. However the literature on sensory variation of fish treated in the same way during production is limited.

1.1.3 Evaluations of sensory quality in the seafood processing chain

Sensory methods are the optimal methods for measuring the sensory quality of seafood products as well as other food products, and it is generally possible to perform sensory tests in all parts of the seafood processing chain. Martinsdóttir et al., (2008) have described sensory evaluations in the seafood processing chain. The description is based on interviews with quality managers in 43 companies in the seafood processing chain, including companies from Iceland, Ireland, Denmark and the Netherlands. 92% of the companies performed sensory evaluations on raw material. Additionally, approximately 75% of the companies performed sensory test of intermediated products and final products. Therefore the results of the interviews clearly showed that sensory evaluations are commonly used. The evaluations are, however, generally not performed in the most optimal way, since sensory quality is rarely described or measured systematically by the companies. Additionally, the results from the evaluations are normally not recorded or shared between different steps in the seafood production chain. Therefore, there is generally no communication of demands, sensory quality, or results from sensory evaluations between the different partners in the chain. However, the companies generally believed that they deliver a quality which satisfies the next customers in the chain, even though terms of sensory quality are almost never used to describe the quality. Furthermore, companies only have little knowledge about the sensory quality demands of the consumers. The use of sensory evaluations in the seafood production chain will be discussed further in Section 3.5.1.

1.2 Salmon and trout

Salmon is the common name for several species of fish including e.g. Atlantic salmon (*Salmo salar*), Chinook Salmon (*Oncorhynchus tschawytscha*), Chum salmon (*Oncorhynchus keta*) and Coho salmon (*Oncorhychus kisutch*), which all belong to the Salmonidae family. Another subgroup of the Salmonidae family has the common name trout. This group includes e.g. Brown trout (*Salmo trutta*) and Rainbow trout (*Oncorhychus mykiss*) (Nelson, 1994).

1.2.1 Consumption and production

Salmon is important in relation to the consumer consumption of fish in many Northern European countries. In Denmark, Sweden, the United Kingdom and Germany, salmon is the third most consumed fish. While salmon is the second most consumed fish in The Netherlands, Norway and France. Trout is generally not as commonly consumed as salmon in many Europe countries, however in Spain and Italy more trout than salmon is consumed. In Denmark trout is the seventh most consumed fish, while it is the sixed or fifth most consumed fish in Germany, Norway and The Netherlands (Welch, 2002).

Atlantic salmon is a very important species, since more than half of the global market for salmon is for Atlantic salmon. Over 90% of the farmed salmon produced is Atlantic salmon and worldwide more than 1,000,000 tonnes of Atlantic salmon are produced in the farming industry every year (Subasinghe and Currie, 2005). Only around 3,000 tonnes per year are caught wild (FAO, 2010a). The largest production of farmed Atlantic salmon is in Norway and Chile. Atlantic salmon is used in production of several products used for human consumption. The most important products are smoked and fresh, and they are whole fish, steaks or fillets (Subasinghe and Currie, 2005).

Rainbow trout is also important species in relation to aquaculture and in 2007 more than 600,000 tonnes of Rainbow trout were produced worldwide in aquaculture. Chile is the largest producer of Rainbow trout, but some countries in Europe, including Denmark, also have considerable production. Rainbow trout is sold for human consumption in many different product types, including fresh, smoked, whole fish, filleted, canned and frozen (Cowx, 2005).

The Chum salmon on the market is generally wild catch, and approximately 300,000 tonnes are caught per year. Two important countries in relation to Chum salmon catches are Japan and the

USA. Chum salmon is mostly used in canned product, but it is also used fresh, dried/salted, smoked and frozen. Furthermore Chum salmon is used in caviar products (FAO, 2010b).
In 2007 around 115,000 and 17,000 tonnes of Coho salmon was produced in aquaculture and caught wild worldwide, respectively (FAO, 2010c). Most of the farmed Coho salmon is produced in Chile (Fairgrieve, 2006), while most of the wild catch Coho salmon is from the USA (FAO, 2010c). Farmed Coho salmon is sold fresh, frozen and smoked (Fairgrieve, 2006).

1.2.2 Sensory characteristics

Similar to other fish types, the sensory quality of salmon and trout is affected by many factors, and some factors are associated with the living fish while others are related to the treatment in the seafood processing chain (Figure 1.1). Factors related to the living fish, which are relevant for salmon and trout, include species, origin, farming conditions, maturation, age and season. Several factors from the seafood processing chain can also affect the sensory characteristics of salmon and trout products. These include different storage methods, storage time and different types of processing, for instance smoking. However since storage methods and time are most relevant for this thesis, only these subjects will be described. The focus will be on storage in ice, frozen storage and storage in Modified Atmosphere (MA). In the following sections the sensory characteristics described are generally of heat-treated samples. If the sensory characteristics are related to other types of samples, this will be described.

1.2.2.1 Species and origin

A few studies have compared the sensory characteristic of different Salmonidae species. Rounds et al. (1992) compared Brown trout and Rainbow trout in a consumer test with 104 families. The results showed that acceptability was more related to origin than to species. Sylvia et al. (1995) compared Chinook salmon and Atlantic salmon using a consumer panel with 189 consumers from Oregon (USA). They overall found that consumers enjoyed wild Chinook salmon significantly more than farmed Atlantic salmon. Furthermore they also compared wild and farmed Chinook salmon and found high overall enjoyment of the wild Chinook salmon. Several other studies have also compared the sensory characteristics of farmed and wild salmon. Farmer et al. (2000) studied the sensory characteristics of frozen farmed and wild Atlantic salmon, and found differences in the texture. The farmed salmon was general more moist, light and less firm than wild Atlantic salmon. However Farmer et al. (1995) did not find any consistent difference between sea-caught farmed and wild Atlantic salmon. Both Farmer et al. (1995) and Farmer et al. (2000) compared river-caught and sea-caught Atlantic salmon. Generally river-caught salmon had high scores of earthy flavour, odour and aftertaste combined with a lower score for salmon-like odour and flavour. Farmer et al. (2000) also included a hedonic rating of acceptability performed by a consumer panel with 40 persons. The results from the hedonic rating mainly showed low consumer acceptability of the river-caught Atlantic salmon compared to the sea-caught Atlantic salmon. While no clear difference between farmed and wild caught Atlantic salmon was observed. However this might be due to the low number of consumers. Skrede and Storebakken (1986) compared the colour of wild and farmed Atlantic salmon by using both sensory analysis and instrumental colour analysis. In the sensory analysis the farmed salmon had a more yellow colour than the wild salmon. In the instrumental analysis no significant differences were found. For Coho salmon it has been reported that the flesh colour of wild Coho salmon was redder and less yellow compared to farmed Coho salmon (Higgs et al. 1989). In the same study no differences were found in odour, flavour and texture.

1.2.2.2 Farming conditions

Numerous of studies have been performed to compare different farming conditions of salmon and trout. One factor of importance is feed composition and several studies have shown that feed composition can influence the sensory characteristics. One significant factor is the lipid source in feed which in several studies been shown to influence the sensory characteristics (Baron et al., 2009; Drobná et al. 2006; Sérot et al., 2002; Skonberg et al., 1993; Thomassen and Røsjø, 1989; Waagbø et al., 1993). For instance Thomassen and Røsjø (1989) found that addition of various vegetable oils to the feed of Atlantic salmon had an effect on odour, taste and colour. According to Waagbø et al. (1993), the texture can also be affected by different fatty acid composition in the feed (obtained by using different oils). Similarly the quantity of lipid in feed can affect the sensory characteristics (Andersen and Steinsholt, 1992; Chaiyapechara et al. 2003; Einen and Skrede, 1998; Regost et al. 2001; Sheehan, et al., 1996). For example Andersen and Steinsholt (1992) found that lipid content influence the colour and taste of Atlantic salmon. The colour is also affected by the feed content of carotenoids (Sigurgisladottir et al., 1994; Skrede et al., 1989).

Furthermore the amount of feeding can affect the sensory characteristics (Einen et al., 1999; Johansson et al., 1995; Johansson et al., 2000). According to Johansson et al., (1995) a reduction in feeding level to 50% of the feeding level needed to obtain the expected maximum growth of Rainbow trout leads to reductions in sensory scores for fresh taste and firmness, while a reduction to 75% did not show any significant effects on the sensory characteristics.

In aquaculture it is normal to starve salmonids for one to two weeks before slaughtering. This is done to clean the digestive tracts and thereby minimize the risk of flesh contamination during the processing (Erikson, 2001). Furthermore, starving before slaughtering reduces the risk of some off-flavours in the fish (Howgate, 2004). Starving can affect the sensory characteristics of Atlantic salmon (Aksnes et al., 1985; Blokhus 1986; Einen and Thomassen, 1998; Mørkøre et al., 2008; Sigholt et al., 1997), Rainbow trout (Johansson and Kiessling, 1991) and Brown trout (Regost et al., 2001). Einen and Thomassen (1998) studied starvation of Atlantic salmon, and found that starvation for 86 days resulted in less fresh flavour and a less hard texture compared to fish starved for 30 days or less. Intensity of acidulous flavour was also affected by starving. Other factors, including stress (Erikson and Misimi, 2008; Mørkøre et al., 2008; Skjervold et al., 2001) and slaughtering method (Kiessling et al., 2004; Özogul and Özogul, 2004), can affect the sensory characteristics of salmonids.

1.2.2.3 Sexual maturation, age and season

Sexual maturation of salmonids can lead to a reduction of sensory quality and maturation is a considerable cause of downgrading of farmed salmon (Michie, 2001). Maturation of Atlantic salmon decreased the colour of the fillets (Aksnes et al., 1986; Blokhus, 1986; Norris and Cunningham, 2004). Furthermore the odour and flavour becomes more neutral, while the texture can become softer (Bilinski et al., 1986), watery and tough (Aksnes et al., 1986). Similarly, Bilinski et al. (1984) found that canned Coho Salmon became discoloured, softer, and exhibited odour and flavour decline duo to sexual maturation. Reid and Durance (1992) studied the effect of maturation on the texture of canned Chum salmon and they found reduction in firmness, dryness, fibrousnesses and chewiness because of maturation.

Also age and season can influence the sensory characteristics. For Rainbow trout increasing age of the fish had been shown to result in increases in total odour intensity, while juiciness decreases (Johansson et al., 2000). According to Mørkøre et al. (2010) both the texture and colour of Atlantic salmon are affected by season, resulting in a long self-life if the fish is harvested at water temperature between 11-15°C (August-October) compared to 6-8°C (February-April). Other studies have also found an effect on texture (Mørkøre and Rørvik, 2001) and colour (Roth et al., 2005) of Atlantic salmon. For Rainbow trout differences in self-life have also been found for the different seasons. According to Wünnenber and Oehlenschläger (2008), self-life of Rainbow trout stored in ice is 14 days during the autumn, while self-life in winter, spring and summer is 16 days.

1.2.2.4 Storage in ice

Fresh, newly slaughtered and gutted, but otherwise whole and not processed Atlantic salmon is characterized by e.g. pearl-shiny skin, clear mucus on the skin, and the fish have a fresh seaweed or neutral odour. The sensory characteristics change over shelf-life. At the end of the self-life, which is 20 to 21 days in ice, the skin becomes yellowish, the mucus is yellow and clotted and the odour is rotten (Sveinsdottir et al., 2003).

The sensory characteristics of Atlantic salmon after cooking also change during the self-life. In the beginning of self-life the odour can be characterized with descriptors such as sourish and cucumber, while the flavour can be described as salmon, metal, sweetish, sourish, fish oil and mushroom. However in the end of self-life after storage in ice these characteristics are hardly detectable and the salmon odour and flavour is characterized of sour, amine, rancid and musty/earth (Sveinsdottir et al., 2002; Sveinsdottir et al., 2003). According to Sveinsdottir et al. (2002) most positive flavour descriptors do not decrease before 17 to 19 days of storage in ice. Similarly the negative descriptors do not increase before 17 to 20 days of ice storage. This is in agreement with the results of Magnussen et al. (1996). Aubourg et al. (2005) studied the development of rancid odour in Coho salmon during storage in ice. They found that rancid odour started to increase after 10 days of storage and after 19 days the rancid odour had raised to a level which was not acceptable for consumption.

The texture also changes as a result of storage in ice. Several studies on different species belonging to the Salmonidae family, including Atlantic salmon, have shown that hardness decreases during storage in ice (Andersen et al., 1997; Azam et al., 1989; Færgemand et al., 1995; Sveinsdottir et al., 2002; Sveinsdottir et al., 2003). The juiciness of cooked Atlantic salmon has also been shown to decrease as a result of storage in ice (Sveinsdottir et al., 2003; Waagbø et al., 1993).

The self-life of fish stored in ice depends on how fast after slaughtering the fish is placed in ice. Rezaei et al. (2008) reported that self-life of Rainbow trout is 9-11 days if the fish is placed on ice immediately after slaughtering. While self-life was 5-7 and 1-3 days if the Rainbow trout first was iced after 4 and 8 hours respectively (before icing, the fish were kept at 18-20°C).

1.2.2.5 Frozen storage

When comparing ice storage and frozen storage it has been shown for both Atlantic salmon (Waagbø et al., 1993; Farmer et al., 2000) and Rainbow trout (Johansson and Kiesslig 1991) that juiciness reduces more during frozen storage. Frozen storage compared to fresh storage can also make the texture firmer (Waagbø et al., 1993). Some changes in sensory characteristics related to the odour and flavour when comparing storage in ice and frozen storage have also been reported. Farmer et al. (2000) found that, for Atlantic salmon, freezing decreased the oily flavour. Waagbø et al. (1993) found increasing off-odour and taste intensity of frozen compared to fresh Atlantic salmon. Johansson and Kiesslig (1991) found that freezing reduced the fresh odour of Rainbow trout. Appearance can also be influenced when comparing frozen and storage in ice (Farmer et al., 2000; Waabø et al., 1993). Wagabø et al. (1993) found increased whiteness in frozen compared to fresh Atlantic salmon.

Conflicting results exist on the effect on the texture of increasing frozen storage time. Farmer et al. (2000) did not find a significant effect on the firm and juicy texture of increased frozen storage time (-24°C) for up to 34 weeks. Also Andersen and Steinsholt (1992), who compared two months to six months of frozen storage of Atlantic salmon, did not find a significant effect of frozen storage time (-13, -18 and -35°C) on the firm and juicy texture. However Refsgaard et al. (1998) found an increase in firm and fibrous texture combined with a reduction of juiciness as a result of frozen storage (-13 and -35°C) for up to 34 weeks of Atlantic salmon.

Increasing frozen storage time can also change the sensory characteristics related to odour and flavour. Andersen and Steinsholt (1992) found the fish oil taste (not defined specifically) was more intense after six months of frozen storage compared to two months of frozen storage. Refsgaard et al. (1998) found that train oil, metal and bitter taste increased during storage, while the intensity of earthy flavour decreased when frozen storage time was increased from 2 to 34 weeks. Rodríguez et al. (2007) studied frozen storage of Coho salmon for up to 15 months at -20°C. They found an increasing rancid odour and flavour, beginning after around 6 months of frozen storage, together with a decrease in fresh odour and taste during the storage period.

However in the study by Farmer et al. (2000) no significant effect on odour, flavour or aftertaste was found on Atlantic salmon when increasing frozen (-24°C) storage time from 2 to 34 weeks. The change in sensory characteristics during frozen storage can also be affected by the type feed used during farming (Baron et al., 2009). Appearance can also be affected by frozen storage time (Farmer et al., 2000; Refsgaard et al., 1998). Refsgaard et al. (1998) found that salmon colour decreased between 2 and 34 weeks of frozen storage.

The effect on sensory characteristics from frozen storage depends on the storage temperature. Refsgaard et al. (1998) compared frozen storage at -10 and -20˚C of Atlantic salmon. The high frozen storage temperature (-10˚C) resulted in faster changes in the taste of the samples. Additionally firmness and fibrousness increased at high frozen storage temperature. However the study did not find any difference in colour and juiciness between the two temperatures. Andersen and Steinsholt (1992) also compared different frozen storage temperatures (-13, -18 and -35˚C) of Atlantic salmon. Similar to Refsgaard et al. (1998) they found that high storage temperature (-13˚C) resulted in a more firm texture compared to the lowest storage temperature (-35˚C). However they also found that fish stored at -35˚C was redder and more juicy than fish stored at -13˚C. Comparable results were observed by Nilsson and Ekstrand (1995) with a more firm and less juicy texture of Rainbow trout stored at -18˚C compared to -40˚C after 18 months.

1.2.2.6 Storage in Modified Atmosphere (MA)

Salmonids products can also be stored packed in Modified Atmosphere (MA), which compared to storage in air (e.g. Fletcher et al., 2002; Pastoriza et al., 1996) or vacuum packing (e.g. Hansen et al. 2009) increases the self-life of the product. Randell et al. (1999) studied the effect of packaging Atlantic salmon fillets in different retail packages including overwrap, vacuum and MA (40% CO_2 + 60% N_2 and 60% CO_2 + 40% N_2). They found that the rancid odour and flavour of cooked fillets were more pronounced in vacuum packed fillets compared to MA packed samples. Hansen et al. (2009) also detected negative odours earlier (sour, off-odours and ammonia) and high end levels in the vacuum packed samples compared to samples packed in MA. Storage in MA has also been shown to reduce development of negative aromas both in Rainbow trout (*Oncorhynchus mykiss*) (Giménez et al., 2002) and Coho salmon (Brown et al., 1980).

Appearance and texture can also be affected by packing in MA. Randell et al. (1999) found that fish packed in MA were redder compared to vacuum packed samples, while they did not observe differences in juiciness or firmness. However Hansen et al. (2009) did find lower firmness of Atlantic salmon fillets packed in MA (60% CO_2 + 40% N_2) compared to vacuum packed. Sivertsvik et al. (2003) found a significant reduction in juiciness and firmness during storage time in MA (60% CO_2 + 40% N_2) of Atlantic salmon fillets.

Studies have also been made on whole Atlantic salmon (Sivertsvik et al., 1999a,b). In these studies, packaging in MA was compared to storage in ice. It was found that the fish stored in MA had an equal or better sensory quality after 13 days of storage.

Self-life of MA packed samples depends on storage temperature. Sivertsvik et al. (2003) compared keeping the MA packed samples at chilled (+4˚C) or super chilled (-2˚C) temperatures. They found that self-life was 10 days for the samples packed in MA and stored at chilled while the self-life was 24 days if the samples were super chilled. In comparison, samples packed in air had a self-life of 7 days if they were chilled and 21 days if they were super chilled. Therefore they concluded that super chilling had more influence on self-life than packing in MA.

The ratio between gas and product in the package has an influence on the self-life of MA salmon products. A high gas ratio increases the self-life of the products (Fernández et al., 2009; Randell et al., 1995). The gas content used for MA packing can also be varied. Fernández et al. (2009) did not find any difference in self-life measured with on a hedonic sensory scale when concentrations of CO_2 and N_2 were varied between 25-90% and 75%-10% respectively. However the microbiological self-life was longer in the samples with high concentration of CO_2. Randell et al. (1995) found a higher overall sensory quality during storage at 2˚C of Rainbow trout packed with 40% CO_2 (60% N_2) compared to 20% CO_2 (80% N_2). According to Fletcher et al. (2004) too high CO_2 levels can result in a poor sensory quality due to a carbonated flavour.

It is also possible to extend the self-life using other packing methods such as including an oxygen absorber which reduces the content of oxygen in the packaging. For instance Mexis et al. (2009) found an increase in self-life of Rainbow trout fillets from 4 days to 13-14 days using an oxygen absorber.

Chapter 2: Materials and methods

This chapter introduces the four experiments which are described in this thesis and a description of the main methods used. A schematic overview of the experiments, including connection to the objective for this work, is shown in Figure 2.1. The figure also shows the relation to the papers included in the thesis. In Sections 2.1 to 2.4 each study is described separately. The descriptions include experiment objective, design, sampling, handling and storage. Sections 2.5 and 2.6 contain a description of the sensory methods and the data analytical methods used in the thesis, respectively. A few other analytical methods, including mechanical texture, pH measurements, determination of lipid and water content, have also been used in the experimental work (Experiment 4). However these methods will not be discussed or described further in this section, although additional information can be found in Paper III.

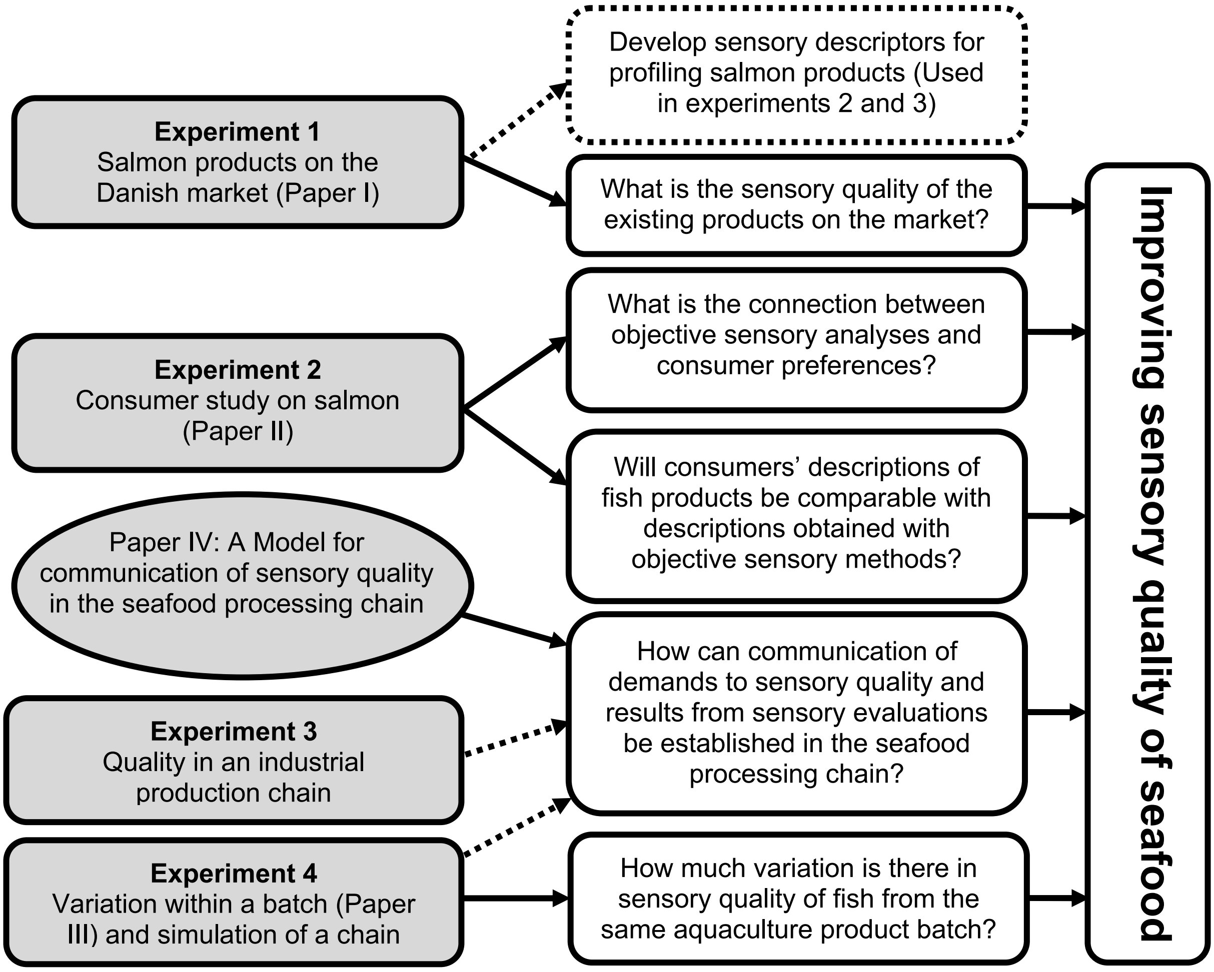

Figure 2.1: Schematic overview of the experiments included in the thesis. The figure includes the connection between the experiments and the objective. Paper IV is a theoretical paper which does not directly include experimental results.

2.1 Experiment 1: Salmon products on the Danish market

The purpose of Experiment 1 was to get an overview of the sensory characteristics of the salmon products available to the consumers on the Danish market. Additionally the purpose of the experiment was to develop a set of sensory descriptors that could be used in further experiments where sensory profiling is to be performed on salmon products. The results from Experiment 1 are described in Paper I, and in Sections 3.1 and 3.2.

The products used in the experiment varied in storage method, storage time, salmon species, whether the salmon was farmed or wild, and if the salmon was portion-sized before storage. An overview of the samples is shown in Table 2.1. All the samples were obtained from local shops or companies and bought as consumer products. Sensory profiling was performed on all samples.

Table 2.1. Overview of the salmon samples used in Experiment 1.

Sample code	Storage method	Storage time	Species[1]	Origin[2]	Cuts for storage, size and packing
MS	MA[3] 2˚C	5 days[4]	*Salmo salar*	Farmed	Pieces of fillets (approximately 125g)
ML	MA[3] 2˚C	7 days[4]	*Salmo salar*	Farmed	Pieces of fillets (approximately 125g)
ISa[5]	In ice 0˚C	7 days	*Salmo salar*	Farmed	Gutted otherwise whole fish (3.5- 4.0kg)
ISb[5]	In ice 0˚C	7 days	*Salmo salar*	Farmed	Gutted otherwise whole (3.5- 4.0kg)
ISc[5]	In ice 0˚C	7 days	*Salmo salar*	Farmed	Gutted otherwise whole (3- 4.0kg)
IL[5]	In ice 0˚C	16 days	*Salmo salar*	Farmed	Gutted otherwise whole (3.5- 4.0kg)
FPS	Frozen	1 month	*Salmo salar*	Farmed	Vacuum packed pieces of fillets (size 140g)
FPL	Frozen	6 months	*Salmo salar*	Farmed	Vacuum packed pieces of fillets (size 140g)
FW	Frozen	6 months	*Salmo salar*	Farmed	Vacuum parked gutted otherwise whole (3-4kg)
WE	Frozen	unknown	*Oncohynchus keta*	Wild	Gutted otherwise whole fish parked in cardboard box (2.5-3.0kg)
Wia	Frozen	unknown	*Oncohynchus kisutch*	Wild	Gutted otherwise whole fish parked in plastic bags (3-4kg)
Wib	Frozen	9 month	*Oncohynchus kisutch*	Wild	Gutted otherwise whole parked in cardboard box (3-4kg)

[1]Common names for the salmon species are Atlantic salmon (*Salmo salar),* Chum salmon (*Oncorhynchus keta*) and Coho salmon (*Oncorhychus Kisutch*).
[2]All farmed salmon are from Norway and all wild salmon are from the Pacific.
[3] Samples packaged in MA (Modified Atmosphere)
[4]The storage time of the fish before it was packed in MA is unknown.
[5]Samples IL, ISa and ISb are from the same fish farm. Sample IL and ISa are from the same batch but have different storage times.

2.2 Experiment 2: Consumer study of salmon

The objective of Experiment 2 was to investigate the connection between objective sensory quality and consumers' preferences for different salmon products. Furthermore the purpose was to compare consumer descriptions of the products with results from the sensory profiling. The experiment included objective sensory analysis and a consumer test of eight salmon products. The consumer test was performed simultaneously in Iceland, Ireland, Denmark and The Netherlands, making it possible to compare consumers' preference between the different countries. The results are described in Paper II and in Section 3.3.

An overview of the experiment is shown in Figure 2.2. The salmon were collected and packed and then sent to the other partners from Denmark. Sensory profiling of the salmon was also performed in Denmark. The experiment was conducted over two weeks. The test weeks had the following time schedule: Monday the products were packed and sent by air to the different partners. Wednesday the sensory profiling was performed and Thursday the consumer test was performed in all four countries. The sensory profiling and the consumer test were for practical reasons not performed on the same day.

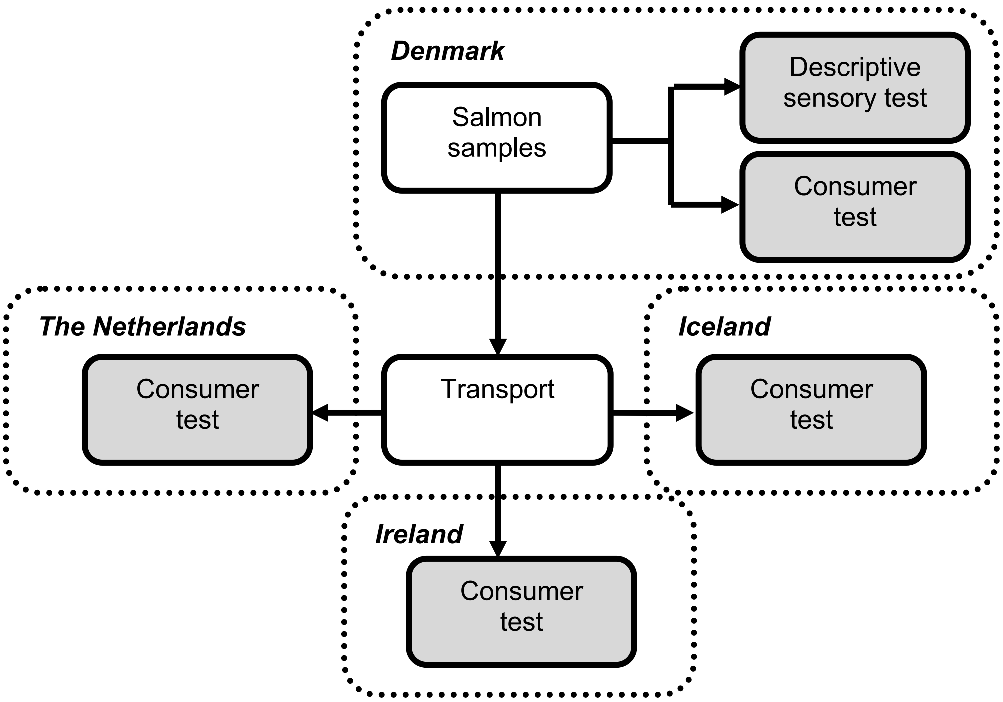

Figure 2.2. Overview of Experiment 2.

Table 2.2 shows a description of the products used in Experiment 2. The products differed in storage method (stored in ice, frozen, packed in MA), storage time, and origin (wild and farmed). Also different salmon species were used (*Salmo salar*, *Oncohynchus keta* and *Oncohynchus kisutch*). The products were chosen in such a way that they represent the most common raw and basic salmon products available to consumers in the test countries.

Table 2.2. Descriptions of salmon samples used in Experiment 2. The table includes sample codes, storage method, storage time, species, origin, and information on the way samples were cut before they were stored. Description of sample codes: WE and WI is wild *Oncohynchus keta* and *kisutch* respectively. F, I and M is frozen, ice storage and packed in MA respectively. L and S stands for long and short storage time, which is depends on the storage method.

Sample code	Storage method	Storage time[1]	Species[2]	Origin[3]	Cuts for storage
WE	Frozen -20˚C	9 month	*Oncohynchus keta*	Wild	Gutted but otherwise whole
WI	Frozen -20˚C	8 month	*Oncohynchus kisutch*	Wild	Gutted but otherwise whole
FL	Frozen -20˚C	5 month	*Salmo salar*	Farmed	Pieces of fillets ready for serving
FS	Frozen -20˚C	1.5 months	*Salmo salar*	Farmed	Pieces of fillets ready for serving
IL	In ice 0˚C	15 days	*Salmo salar*	Farmed	Gutted but otherwise whole[4]
IS	In ice 0˚C	8 days	*Salmo salar*	Farmed	Gutted but otherwise whole[4]
ML	MA[5] 2˚C	7 days on ice + 8 days in MA	*Salmo salar*	Farmed	Pieces of fillets ready for serving[6]
MS	MA[5] 2˚C	3 days on ice + 6 days in MA	*Salmo salar*	Farmed	Pieces of fillets ready for serving[6]

[1] Storage time before the consumer test.
[2]Common names for the salmon species are Chum salmon (*Oncorhynchus keta*), Coho salmon (*Oncorhychus Kisutch*) and Atlantic salmon (*Salmo salar).*
[3]All farmed salmon are from Norway and all wild salmon are from the Pacific.
[4]3 days before the consumer test, the fish were filleted. Fillets were packed in plastic bags which were stored at 0˚C.
[5] Packed in MA. Gas mixture was 40% CO_2 and 60% N_2.
[6]Before packing in modified atmosphere the fish were stored gutted but otherwise whole.

2.3 Experiment 3: Quality in a seafood processing chain

The objective of Experiment 3 was to study how sensory quality in one part of a real seafood processing chain affects the sensory quality in another part of the chain. This provides a practical example of why it is important to relate and communicate sensory quality in one point of the seafood production chain to another part for the seafood production chain. The experiment was performed by following the production for MA packed salmon in a Danish fish processing company. The results from Experiment 3 have not been published, but the results are discussed in section 3.5.4.

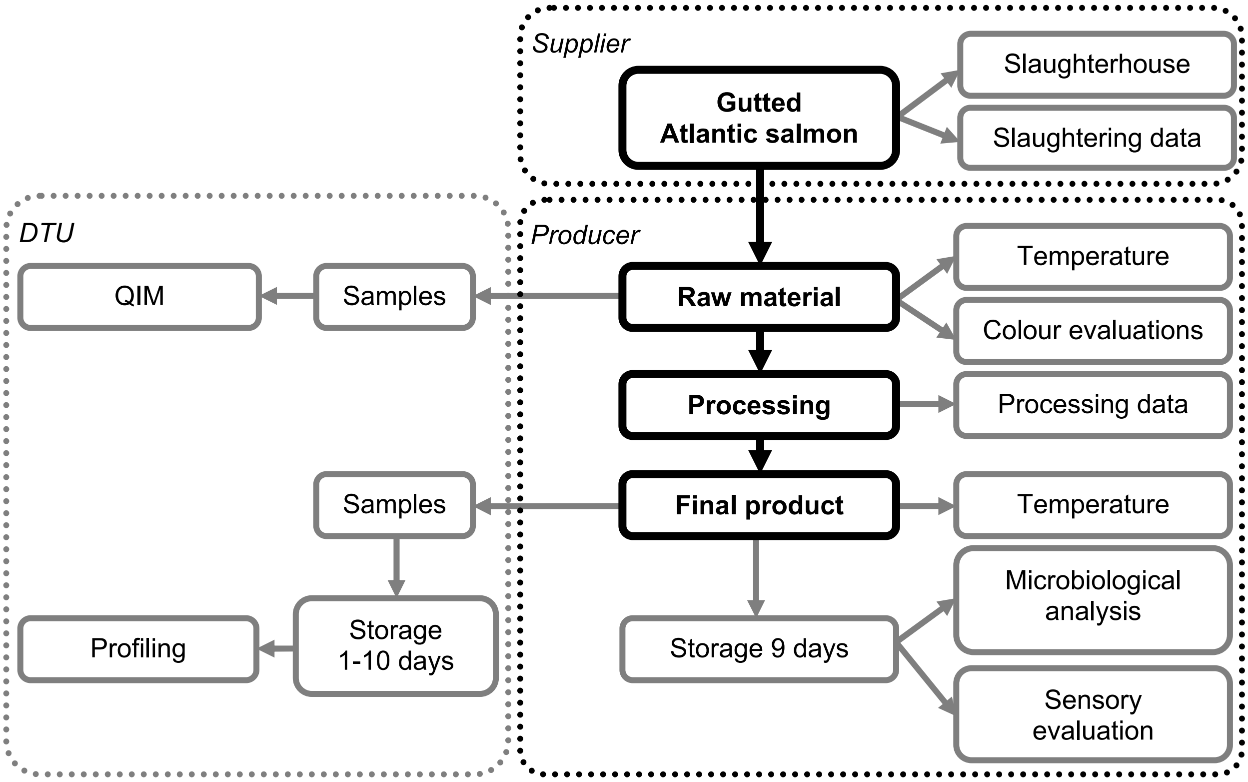

Figure 2.3: Overview of Experiment 3. MA is Modified Atmosphere. The black boxes and arrows show the production chain. Grey boxes and arrows show where different analyses are performed by the producer and by DTU. The grey colour also illustrates the other information available for each batch.

An overview of the experiment design is shown in Figure 2.3. The experiment focuses on the different steps at the producer. However some information about the origin of the raw material was also available. In total six batches (A, B, C, D, E and F) of raw material farmed Atlantic salmon (*Salmo salar*) from Norway were followed in the production. Before the salmon was processed, temperature was measured and also a colour evaluation was made. The colour evaluation was made by one or two persons using the SalmoFan colour scale (Skrede et al., 1990). Samples of the raw material (whole gutted fish) were sent to DTU Aqua. The rest of the batches were used in the processing, which first included filleting and trimming. Afterwards they were cut in pieces ready for serving and packed in MA (the composition of the MA is not described, as agreed with the processing company). The pieces of salmon were without bones but with skin. The temperature was measured of the final product. Samples of the final product were sent to DTU. Additional samples were stored (2°C) for 9 days at the processing company (9 days corresponds with the maximum shelf-life of MA salmon from the processing company). Sensory and microbiological evaluation were performed by the company on these samples. This evaluations were part of the companies' normal quality assurance system, together with the colour and temperature measurements.

The sensory evaluations carry out by the company were performed by one or two experienced employees at the company. The sensory method used by the company included one overall evaluation of odour and flavour after the samples were cooked. In the evaluations odour and flavour was measured on a special designed scale (one scale for odour and one scale for flavour). The purpose of the test was to determine if freshness was acceptable at the end of shelf-life. In respect of the wishes of the company, this sensory evaluation method will not be described in further detail. Similarly, the precise microbiological measurements that were performed by the company will not be described further.

The samples of raw material which were sent to DTU were evaluated with QIM (10 fish from each batch). While samples of the final product (salmon packed in MA) were evaluated with sensory profiling at two or three different storage times for each batch. All storage times were between 1 and 10 days in MA.

2.4 Experiment 4: Variation within a batch and simulation of a chain

There were two objectives with Experiment 4. Firstly the objective was to study whether there can be significant variations in objective sensory profiles of fish from the same aquaculture production batch. Including studding if there can be sensory differences between groups of fish collected at different times during a production day. Thereby provide knowledge to answer the question: How much variation is there in the sensory quality of fish from the same aquaculture product batch? The results from this part of experiment are published in Paper III and discussed in Section 3.4.

Secondly the objective with this experiment was to simulate part of an industrial seafood production chain including sensory evaluations, and using the results to illustrate the importance of relating and communicating sensory quality in different parts of the seafood processing chain. The results from this part of the experiment have not been published, but they are discussed in Section 3.5.5.

The experiment was performed on farmed Rainbow trout (*Oncorhynchus mykiss*) which all came from the same fish farm and production batch. An overview of the experiment is show in Figure 2.4. Furthermore Figure 2.5 shows how the experiment can be used to simulate an industrial production of minced Rainbow trout, which could be further processed into a convenience meal e.g. salmon pie.

A total of 16 fish were picked out of the production three times at hourly intervals during a production day. This resulted in three groups X, Y and Z. The fish were packed in ice and transported to DTU where they were stored in ice (0°C) for 3, 10 and 17 days respectively. Ten fish from each group were stored for 3 days, while 3 fish were stored for 10 and 17 days respectively. Only results from fish which were stored for 3 days were used in relation Paper III and Section 3.4, while all fish were used in relation to Section 3.5.5.

After the storage period all fish were weighed, the length was measured and QIM evaluations were made. Then the fish were frozen at -30°C for between two and three months. The next part of the experimental work was carried out over a five weeks period. On each experimental day during this period of time three or four fish were evaluated (there way 3 experiment days during each week).

The fish were thawed at 2°C for three days before the experimental day. Afterwards the fish were filleted and trimmed. A sample (5 cm wide) under the dorsal fin was cut out on each fillet. These two pieces from each fish were divided in two and used to measure texture. The rest of the fillets were cut in strips (diameter approximately 3cm) and the strips from each fish were mixed manually before they were minced on a mincing machine (leek size 5mm). The mince was again mixed manually. Then samples from the minced fish were taken out to determine lipid, water content and pH. The rest of the minced fish was used in the sensory profiling which was performed on the same day as the fish was minced (the experiment day).

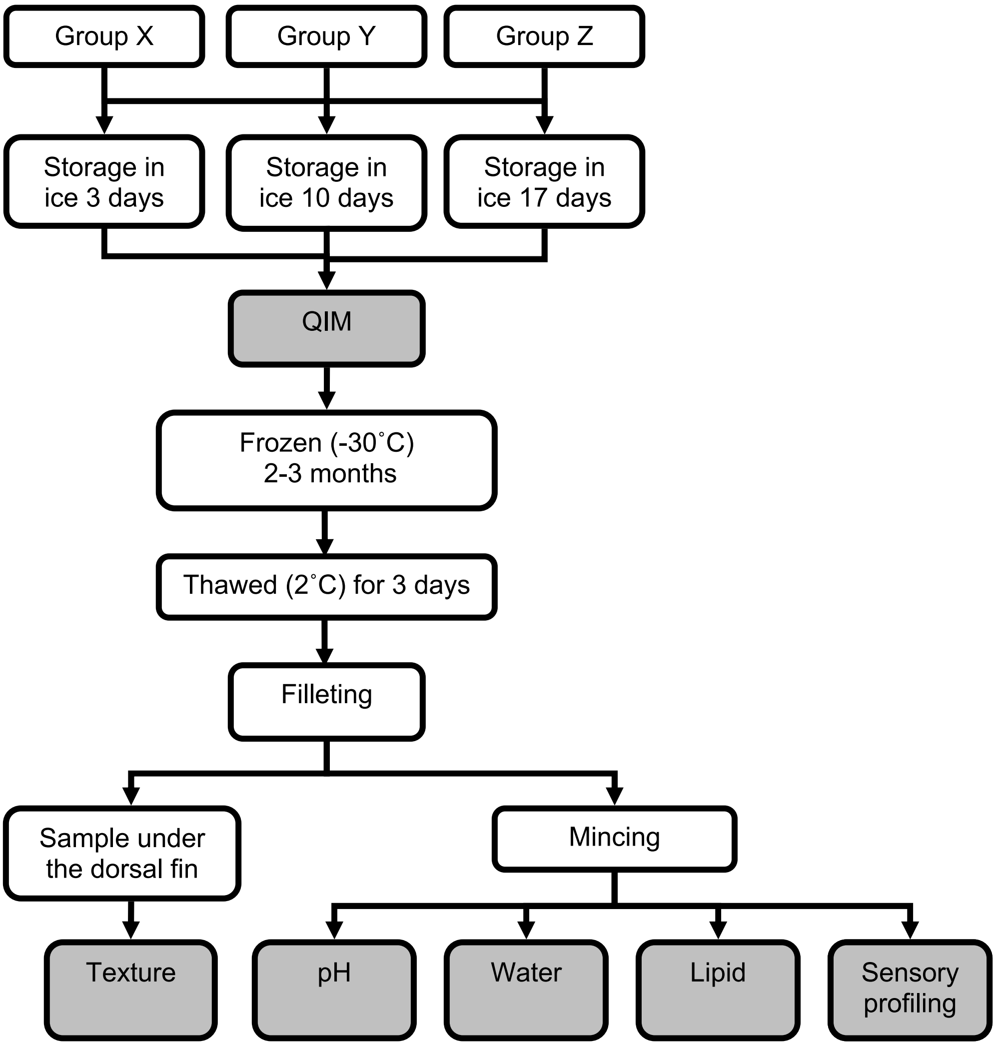

Figure 2.4: Overview of the experimental design for Experiment 4. The grey fields outline the different measurements performed in the experiment.

In the sensory profiling a reference sample was used. The reference samples were made of trout (*Oncorhynchus mykiss*) from the same farm as the fish in the study, but from another production batch and production day. In total 21 fish were used to produce the standard. All these fish were stored 3 days on ice before they were filleted and cut in strips (approximate diameter 3 cm). The strips from all 21 fish were mixed together. Then the strips were minced and afterwards mixed in the same way as the fish used in the study. The minced fish meat was frozen in vacuum packed plastic bags at -80°C until the study was performed.

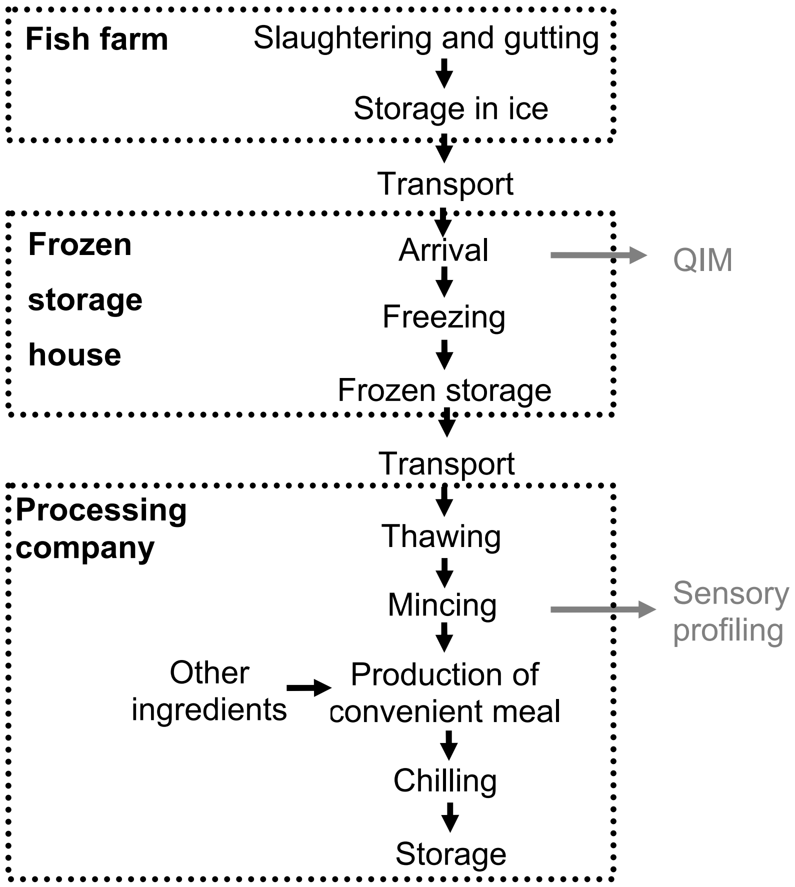

Figure 2.5: Illustration of the simulated seafood production chain in Experiment 4. The experiment only simulates the production chain until the fish is minced, including the sensory profiling. Furthermore the whole production chain is not included in the figure since the distribution of the convenience meal e.g. in shops and at the consumer is not included.

2.5 Sensory Methods

In this thesis several sensory methods are used. These methods include sensory profiling, QIM and consumer tests.

2.5.1. Sensory profiling

Sensory profiling is used in all four experiments described in the thesis in order to obtain detailed sensory descriptions of the products. There are several examples where descriptive sensory profiling has been used on fish, including Atlantic salmon (e.g. Bjerkeng et al., 1997; Farmer et al., 2000) and Rainbow trout (e.g. Francesco et al., 2004; Johansson et al., 2000).

It is essential to use assessors which have been selected based on their ability to use their senses when performing sensory profiling. Furthermore assessors must be specifically trained for the evaluation in which they are participating (Lawless and Heymann, 1998). Normally the sensory panel, in collaboration with the panel leader, develop a set of descriptors which can describe the sensory differences of the relevant samples. In the evaluations each descriptor is evaluated for each sample on a scale. In this work a 15 cm unstructured scale, anchored 1.5 cm from both ends, was used. The descriptors used in this work are shown in Table 2.3. The evaluations were performed by each individual assessor (Lawless and Heymann, 1998).

In all experiments samples were served as replicates in randomized order. Samples were placed in porcelains trays with a lid marked with a randomized 3-diget code. Samples were all heat treated in a convection oven until the core temperature had reached 70°C. In Experiments 1, 2 and 3, samples were pieces of fillets, but in Experiment 4 the samples were minced and shaped as a semi-sphere before the heat treatment. In Experiment 4 the first sample served in all sessions was a reference sample, making it possible for assessors to recalibrate their senses on each descriptor and the scales. The reference was also served code and in between the other samples.

Table 2.3. Descriptors used for sensory profiling of salmon (Experiments 1 to 3) and Rainbow trout (Experiment 4).

Descriptor	Explanations	Scale		Experiment			
		Minimum (0 cm)	Maximum (15 cm)	1	2	3	4
Odour							
Seaweed	Fresh seaweed, fresh sea smell	None	Strong	X	X	X	-
Sourish	Acidic, fresh citric acid	None	Strong	X	X	X	X
Sweet	Sweet	None	Strong	X	X	X	X
Rancid	Rancid fish, paint, varnish	None	Strong	X	X	X	-
Sour	Sour dishcloth/ sour sock	None	Strong	X	X	X	-
Cooked potatoes	Cooked peeled potatoes	None	Strong	-	-	-	X
Wet dog	Wet dog	None	Strong	-	-	-	X
Warm milk	Warm milk but not boiling milk	None	Strong	-	-	-	X
Sickly sweet	As rotten fruit	None	Strong	-	-	-	X
Appearance							
Discoloured	Brown or yellow spot, dark areas	None	Strong	X	X	X	-
Colour	Salmon colour	Light	Dark	-	X	X	-
Salmon colour	Evaluated with a SalmoFan ruler[1]	_	_	X	-	-	-
Texture							
Juicy	The ability of the samples to hold water after 2-3 chews	Dry	Juicy	X	X	X	X
Firm	Force required to compress the sample between the molars	Soft	Firm	X	X	X	X
Oily	Amount of fat coating in the mouth surfaces	None	Strong	X	X	X	X
Flavour							
Fresh fish oil	Fresh oil, fresh green hazelnut	None	Strong	X	X	X	X
Sweet	Sweet, hot milk	None	Strong	X	X	X	X
Sourish	Acidic, fresh citric acid	None	Strong	X	X	X	X
Cooked potatoes	Cooked peeled potatoes	None	Strong	X	X	X	X
Mushroom	Mushroom flavour	None	Strong	X	X	X	X
Rancid	Rancid fish, paint, varnish	None	Strong	X	X	X	-
Salt	Salt	None	Strong	X	X	X	-
Cooked potatoes	Cooked peeled potatoes	None	Strong	-	-	-	X
Sour	Sour dishcloth, sour sock	None	Strong	-	-	-	X

[1]Evaluated with a SalmoFan ruler (F. Hoffmann-LaRoche Ltd., Basel, Switzerland) on an interval scale from 20 to 34, where 20 is lighter salmon colour (pink) than 34.

2.5.2 Quality Index Method (QIM)

The QIM is a sensory method which is used for evaluating freshness of gutted whole raw fish stored in ice (Bremner, 1985). However, it is also possible to develop QIM schemes that can be used to evaluate freshness in thawed whole fish (Hyldig and Nielsen, 1997) and fillets (Herrero et al., 2003). In this work QIM is used in Experiments 3 and 4 to evaluate freshness of ice stored, gutted whole Atlantic salmon (*Salmo salar*) and Rainbow trout (*Oncorhynchus mykiss)* respectively.

Table 2.4: Quality Index Method (QIM) scheme, used in Experiment 3, to evaluate farmed Atlantic salmon (*Salmo salar*). Detailed descriptions of each quality parameter and relation to points can be found in Sveinsdottir et al. (2003).

Quality parameters		Points
Skin	Colour/appearance	0 -2
	Mucus	0 - 2
	Odour	0 - 3
	Texture	0 - 2
Eyes	Pupils	0 - 2
	Form	0 - 2
Gills	Colour/appearance	0 - 2
	Mucus	0 - 2
	Odour	0 - 3
Abdomen	Blood in abdomen	0 - 1
	Odour	0 - 3
Quality index		0 - 24

Table 2.5: Quality Index Method (QIM) scheme, used in Experiment 4, to evaluate farmed Rainbow trout (*Oncorhynchus mykiss)*. Detailed descriptions of each quality parameter and relation to points can be found in Green-Petersen et al. (2010).

Quality parameters		Points
Skin	Colour/appearance	0 - 2
	Mucus	0 - 1
	Odour	0 - 2
	Texture	0 - 2
Eyes	Pupils	0 - 2
	Form	0 - 2
Gills	Colour	0 - 2
	Mucus	0 - 2
	Odour	0 - 3
Abdomen	Blood in abdomen	0 - 1
	Odour	0 - 2
Quality index		0 - 21

QIM is based on the typical changes that occur in raw fish during storage in ice. These changes are described in a QIM scheme and since the change varies from one species to another, QIM schemes have been developed for the individual fish species (Hyldig and Green-Petersen, 2004). QIM schemes have been developed for several species e.g. herring, cod, plaice and Atlantic salmon (Martinsdóttir et al., 2001). An overview of the QIM scheme for Atlantic salmon (used in Experiment 3) and Rainbow trout (used in Experiment 4), is shown in Tables 2.4 and 2.5 respectively. The QIM schemes contain a set of parameters which are evaluated by the assessors. For each parameter 0, 1, 2 or 3 demerit points are given depending on which description best explains the appearance, texture or odour of the fish. The total score of demerit points is called the Quality Index (QI). If the QIM schemes are constructed appropriately, a linear relationship will exist between QI and the storage time in ice (Hyldig and Green-Petersen 2004). The main advantages in using QIM are that it is non-destructive and it takes into account differences between species.

The assessors performing the QIM evaluations in both Experiments 3 and 4, were trained in QIM evaluations on Atlantic salmon and Rainbow trout respectively. This is similar to in the sensory profiling essential for the reliability of the results. In the QIM evaluation in Experiments 3 and 4 the number of assessors used was five (three to five assessors participated in each session) and four respectively (three or four assessors participated in each session). In the QIM evaluation each assessor evaluated all fish individually. In both experiments the QIM evaluations were performed at the laboratory at DTU. During the evaluations the fish were placed on cooled bricks and in daylight. The fish were marked with randomized 3-digit codes and placed in random order.

2.5.3 Consumer tests

Sensory consumer tests can be used to find consumers' preferences based on the sensory impression of a product. A consumer test was performed in Experiment 2.

Sensory consumer tests are subjective. Therefore the demands on participants are considerably different from the demands on assessors in sensory profiling and QIM. The import factor when finding participants for consumer tests is that they belong to the population of interest. Therefore participants should be frequent users of the product, since they are most likely to form the target market and will be familiar with similar products (Lawless and Heymann, 1998). In Experiment 2 there were two criteria to the participating consumers. The first criteria was that the participating consumer had to eat fish at least once a month, thereby ensuring that consumers who never eat fish did not participate. The second criterion was that the consumers were at least 18 years old.

The consumer test in Experiment 2 was performed as a central location test, with four test places (one in each country). Approximately 120 consumers were recruited from the local population around the four test locations in each country. During the test days several sessions were held in each country and all consumers participated in one session during each test day. The most import argument for performing the test as a central location test was that it would have raised additional logistical problems to perform the test as a home-use test. Additionally more products can be tested in central location tests (Meilgaard et al., 2007). Central location tests also have other advantages compared to home-use tests, for instance a higher percentage of returned responses can be expected, misunderstandings can be cleared up during the test, and the risk that consumers just fill out the questionnaire without actual testing the products is smaller. Samples can also be prepared in the same way in a central location test. On the other hand, in home use tests consumers can prepare and use the samples the way that they prefer or normally do.

In Experiment 2 samples were heat treated without additives and the samples were served without other food items (besides water). Consumers were sitting alone and were not allowed to speak during the tasting. Serving order was randomized between countries and session. Consumers were asked two questions about each sample in the test. The first question was "Overall liking of the product?" This question was answered on the 9-point hedonic category scale (Peryam and Girardot, 1952), which according to Lawless and Heymann (1998) is the most commonly used hedonic scale. The second question was "Why did you make this choice?" This question was an open-ended question, where consumers had a chance to explain their choice in their own words. The main advantages of using open-ended questions are that they can give insights to opinions about the products with a minimal risk of affecting the consumers' attitudes. However interpretation of open-ended questions might be difficult and pose a risk of misunderstandings. Furthermore, some groups of consumers give more detailed answers than other groups (Lawless and Heymann, 1998). However it has been show that it is possible to analyse consumers' comments and obtain valuable information about the products (Faye et al., 2006; Kleij and Musters, 2003).

2.6. Data analysis

Several data analysis methods have been used in the analysis of the results from the different experiments. This section will focus on Principal Component Analysis (PCA), Partial Least Squares Regression (PLSR) and cluster analysis. PCA is a fundamental method in multivariate data analysis, which is generally used to get an overview of data, e.g. results from a sensory profiling, and to identify outliers. PCA has been used in Papers I, II and III. PLSR is used to relate two sets of data by regression. The two data sets can for instance be results from an objective sensory profiling and consumer preferences on the same samples. Both PCA and PLSR have been used in Papers I, II and III, but also in relation to data analysis of the unpublished results. Cluster analysis has been used in this paper to identify clusters of consumers which have different patterns of preference.

2.6.1 Principal Component Analyses (PCA)

In PCA the goal is to find the underlying structure of data by dividing the data matrix (**X**) into a signal and a noise part. The data matrix contains of a number of objects (n) and some variables (p) e.g. sensory descriptors from a sensory profiling. The fundamental principle in PCA is to extract Principal Components (PCs) from the data matrix. The data matrix (**X**) can be thought of as a swarm of data points in a multivariate space. The first PC (PC1) is placed through the swarm of data points in the direction which describes the largest systematic variation in the data. The second PC (PC2) is placed through the direction describing the largest systematic variation in the rest of the data and it is orthogonal to PC1. This continues until all systematic variation in the data has been described (Wold et al., 1987; Bro 1996). Loadings are the direction of the PC in the original multivariate space which is defined by the original p variables. Consequently loadings describe the relationship between the original p variables and the PC´s. Scores however describes the relationship between the objects n and the PCs. The relationship between the data **X** and the PCA model can be described in the following way: $\mathbf{X} = \mathbf{TP^T} + \mathbf{E}$. $\mathbf{TP^T}$ is the PCA model, were **T** is the score matrix and $\mathbf{P^T}$ is the transported loading matrix. **E** is the "noise" part, which should not contain any systematic variation of data and is not explained by the model (Esbensen, 2000).

2.6.2 Partial Least Squares Regression (PLSR)

In PLSR the goal is to establish a model which can describe the relationship between two data matrixes (**X** and **Y**), were **X** consists of more than one variable but **Y** can be one or several variables. After the PLSR model has been established it can be used to predict future values of **Y** from the variables in **X**. In PLSR the data structure in **X** which is relevant for the data structure in **Y** is extracted. Like in PCA a new set of components is placed in the swarm of data points in the multivariate space described by **X**. These components are PLS components, and they are placed in the direction where there is most co-variation between **X** and **Y** (Martens and Jensen, 1983; Bro 1996; Esbensen, 2000).

2.6.2.1 Level correction and reliability of sensory profiling data

In this work PLSR is used to remove level effects on data from sensory profiling data. Level effects occur because sensory assessors use the scales differently (Meilgaard et al., 2007). The removing of the level effects is done by making a PLSR model were the **X** is the assessors and **Y** is the sensory data. This model describes the differences between the assessors, which are generally not of interest. However the Y-residuals from the model contain the part of the sensory profiling data which is not explained by the model and therefore also contains the information which is normally of interest (differences between samples). Therefore the Y residuals are used in further analysis of the data (Thybo and Martens, 2000).

Furthermore PLSR is used to study the reliability of each assessor, sample and descriptor used in a sensory profiling (only results from the descriptors are described in the thesis (Section 3.1)). This is done by calculating the signal to noise rations (S/N) for each assessor, sample and sensory descriptor. From a PLSR model of the level corrected results from the sensory profiling the Signal (S) is the initial variance at zero PLS-components while the Noise (N) is the residual variance for the model with the optimal number of PLS-components (the variation not explained in model) for each assessor, sample and descriptor. Therefore a S/N lower than one indicates that the assessor, sample or the descriptor are dominated by noise and their values therefore not a reliable. However if the S/N for a descriptor, assessor or sample is higher than one, the descriptor has discriminating power (Thybo and Martens, 2000).

A considerable advantage when removing level effects and studying S/N ratios is that the calculation can handle missing values. Missing values can for instance arise if an assessor is not evaluating all samples, and missing values is a frequently accruing phenomenon in sensory data.

2.6.3 Validation of PCA and PLS models

Validation is essential aspect of multivariate analysis since it ensures the reliability of the model. In this work cross validation have been used. When using cross validation one sample (full cross validation) or a group of samples (segmented cross validation) are taken out of the data one by one before the model is calculated. Thereby a number (which is identical to the number of samples or groups) of sub-models is calculated, and the residuals from the sub-models are used to calculated the total residual validation. One main aspects of validation is to determine the optimal number of components. If too few components are used some systematic variation is not explain in model (under fitting). Alternatively if too many components are used some noise will be included in the model (over fitting). The optimal number of components can be desired by studying the explained and residual variation. Another method in PLSR modelling to determine the optimal number of components is to study the Root Mean Square Error of Prediction (RMSEP).

2.6.4 Cluster analysis

Several clustering methods exist (Jacobsen and Gunderson 1986), and in this work K-means clustering (MacQuenn, 1967) was used. K-means clustering is a non-hierarchical clustering method and before the calculation the number of clusters needs to be selected. Each observation (in this case each consumer) is assigned to a cluster based on its distance from the centre of the cluster. The centre of the cluster is the average of all the observations in the cluster. As more observations are added to the clusters the centre moves. Therefore assignment of the observations must be repeated until no further changes occur (Meilgaard et al., 2007; Vandeginste et al., 1998). Wajrock et al. (2008) performed a comparison of several different clustering methods used on preference data, and according to their results K-means clustering gave better results than several of the other methods.

Before the clustering analysis in Experiment 2 (Paper II) the consumers' liking scores were centred. By doing this differences in which part of the scale the consumers use are removed. If raw data are used in cluster analysis normally clusters will appear where the main difference is which part of the scale they use.

Chapter 3: Main results and discussion

This chapter presents the results and discussions of results from Papers I to IV together with unpublished results (from Experiment 3 and 4). Section 3.1 contains a discussion of the set of sensory descriptors developed in Experiment 1, and also used in Experiments 2 and 3. Section 3.2 contains a description of sensory variation in salmon products available to consumers (Experiment 1). Section 3.3 contains the results from Experiment 2. In this section consumer preference of salmon products is discussed, consumers' descriptions of salmon products are compared with objective sensory descriptions obtained with sensory profiling, and the influence of objective sensory quality on consumers' preferences of salmon products are also described. Section 3.4 contains a description of the variation in sensory quality of fish belonging to the same aquaculture production batch (Experiment 4). Section 3.5 describes the importance of communicating demands to sensory quality and results from sensory evaluations in the seafood production chain. The section suggests how communication of sensory quality in the chain could be established. Additionally unpublished results from Experiments 3 and 4 are described in this section.

3.1 Sensory descriptors for describing salmon products

A set of sensory descriptors (Table 2.3) for sensory profiling of salmon was developed and used in Experiment 1 (Paper I). The descriptors were also used in Experiments 2 and 3. However one modification was made regarding the definition of the descriptor salmon colour in Experiments 2 and 3 compared to Experiment 1. In Experiment 1 salmon colour was measured using a SalmoFan ruler (F. Hoffmann-LaRoche Ltd., Basel, Switzerland) which has an interval scale. However in Experiments 2 and 3 salmon colour was evaluated on the same scale as the other sensory descriptors (15 cm unstructured scale, anchored 1.5 cm from both ends and the end points were marked light and dark). The reason for this was that in Experiment 1 it was found that the sensory panel only used a rather little interval on the SalmoFan ruler (evaluations between 20-28 was made, and 86% of the evaluations were between 20 and 23). Furthermore using the same scale as the other sensory descriptors gave some advances in relation to data analysis and level correction.

In Experiments 1 and 2 the descriptors were used to profile samples with differences in origin, storage time, storage method and species. While the descriptors in Experiment 3 were used to profile Atlantic salmon stored in MA for 1 to 10 days. The set of sensory descriptors was able to describe differences in sensory characteristics between the samples in both Experiment 1 (Paper I and Section 3.2), Experiment 2 (Paper II and Sections 3.3.3 and 3.3.4) and Experiment 3 (Section 3.5.4). However in Experiment 2 it could have been relevant to have additional descriptors in relation to texture, since the analysis of the consumer comments showed that there were differences between the samples in the consumers' use of comments related to tender, tough and rubber texture (see Section 3.3.3).

The reliability of each descriptor has been analysed using the signal to noise ratio (S/N) (Thybo and Martens, 2000). Table 3.1 shows the signal to noise ratio (S/N) for the different sensory descriptors in Experiments 1, 2 and 3. Generally, descriptors in Experiment 2 were most reliable, while the descriptors in Experiment 3 were the least reliable. The reason for this is probably that there were less sensory differences between the samples in Experiment 3 than in Experiments 1 and 2. In all three experiments the descriptors which are most reliable according to the S/N are colour, firm and oily texture. In Experiments 1 and 2 juicy texture also has a high S/N ratio. The most reliable odour descriptor in both Experiments 1 and 2 was sea/seaweed. The flavour descriptors in Experiment 2 generally had higher reliability than in Experiment 1, and in both experiments fresh fish oil flavour had the highest reliability.

Table 3.1: Signal to noise ratio (S/N) for each sensory descriptor in Experiments 1 (Paper I), 2 (Paper II) and 3. Descriptors with an S/N lower than one are dominated by noise and their values therefore not reliable. If the S/N for a descriptor is higher than one, the descriptor has discriminating power.

Descriptor	Experiment 1	Experiment 2	Experiment 3
Odour			
Sea/seaweed	1.07	1.22	0.99
Sourish	1.00	1.05	0.99
Sweet	1.00	1,08	1.00
Rancid	1.00	1.07	1.00
Sour	1.00	1.04	0.98
Appearance			
Discoloured	1.29	1.14	0.94
Salmon colour	-	1.46	1.15
Texture			
Juicy	1.49	1.11	1.00
Firm	1.27	1.31	1.12
Oily	1.37	1.18	1.04
Flavour			
Fresh fish oil	1.43	1.60	0.98
Sweet	1.05	1.15	1.00
Sourish	0.97	1.10	1.00
Cooked potatoes	1.00	1.09	1.00
Mushroom	1.05	1.40	1.00
Rancid	1.06	1.49	0.99
Salt	1.05	1.20	1.00

3.2 Sensory variation in salmon products available to consumers

Experiment 1 included a comparison of the sensory characteristic of salmon products available to consumers on the Danish market (Paper I). Figure 3.1 shows scores and correlation loadings from the first two PCs from a PCA model calculated on the results. The PCA model includes all other sensory descriptors than salmon colour. PC1, which explains 73% of the variation in the data, is greatly influenced by frozen storage time. All the ice and MA samples plus FPS (Atlantic salmon frozen for 1 month*)* and WE (Chum salmon frozen) sample have high PC1 scores. This group of samples has not been frozen, or only frozen for short period of time (the frozen storage time of sample WE is unknown). Sample FPL and FW (both are Atlantic salmon frozen for 6 months) have medium-low PC1 scores and medium frozen storage times. WIa and WIb (both frozen samples of Coho salmon) have low PC1 scores and high frozen storage times (WIb was frozen for 9 months while the frozen storage time of WIa is unknown). A low PC1 score is correlated with firm texture, discoloured appearance and rancid flavour, and negatively correlated to sea/seaweed odour, juicy and oily texture, fresh fish oil, sweet and mushroom flavour. The results show that especially the texture and flavour of the salmon, but also the increase in discoloured appearance and decrease in sea/seaweed odour, were observed as a consequence of increased frozen storage.

That texture becomes more firm (Waagbø et al., 1993) and less juicy (Johansson and Kiesslig 1991; Farmer et al., 2000; Waagbø et al., 1993) because of frozen storage compared to storage in ice have also been found in other studies. Furthermore Refsgaard et al. (1998) found that firm and fibrous increased while juiciness was reduced during frozen storage for up to 34 weeks of Atlantic salmon. However Farmer et al. (2000) did not find a significant effect of increased frozen storage time for up to 34 weeks on firm and juicy texture. Also Andersen and Steinsholt (1992), who compared 2 months to 6 months of frozen storage of Atlantic salmon did not find a significant effect of frozen storage time on firm and juicy. It has also been shown in other studies that the appearance can change during frozen storage (Farmer et al., 2000; Waagbø et al., 1993). In relation to the odour and flavour, Farmer et al. (2000) found that freezing of Atlantic salmon only had little influence on flavour. Additionally they did not find any significant effect of freezing storage time of between 2 and 34 weeks on odour, flavour, and aftertaste. However, Refsgaard et al. (1998) found a significant decrease caused by freezing time on the sensory descriptor fish oil taste of Atlantic salmon. This was also observed in the present study.

Refsgaard et al. (1998) found that train oil, metal and bitter taste increased while the intensity of earthy flavour decreased during frozen storage for up to 34 weeks. In other studies it has also been observed that odour and flavour change during frozen storage time (Rodríguez et al., 2007; Waagbø et al., 1993). The change occurring during frozen storage depends on storage temperature. Generally high frozen storage temperature results in faster change in sensory characteristics (Andersen and Steinsholt, 1992; Nilsson and Ekstrand, 1995; Refsgaard et al. 1998).

Three of the frozen samples were wild salmon and these were also of other species than the rest of the samples in Experiment 1 (Table 2.1). The two samples of Coho salmon (WIa and WIb) had rather similar sensory properties, but sample WIb had a darker colour than sample WIa (Paper I). This may be due to differences in e.g. feed and maturation. However samples were very different from the rest of the samples. The sample of Chum salmon (WE) was not very different from many of the samples of Atlantic salmon, including the ice-stored samples, MS (Atlantic salmon stored for 5 days in MA) and FPS (Atlantic salmon frozen for 1 month as pieces of fillets) (Figure 3.1). These could indicate that the sensory properties of Chum salmon and Atlantic salmon are fairly similar, but rather different from the sensory properties of Coho salmon. However this finding is in conflict with the results from Experiment 2 (described in Section 3.3.3, Section 3.3.4 and Paper II), where the sample of Chum salmon is rather different from the sensory profile of the Atlantic salmon samples. Furthermore the sample of Chum Salmon in Experiment 2 is much more similar to the profile of samples of Coho salmon (WIa and WIb) in Experiment 1, than to the sensory profile of the Chum salmon sample in Experiment 1. For instance the texture of the Chum Salmon sample from Experiment 2 has a high intensity of firm but a low intensity of juicy and oily (Figure 3.2). The main explanation for this is probably related to differences in frozen storage time or other treatment. Therefore further experiments, which include samples that have been treated in more similarly, need to be done to obtain more knowledge about sensory differences between the three salmon species.

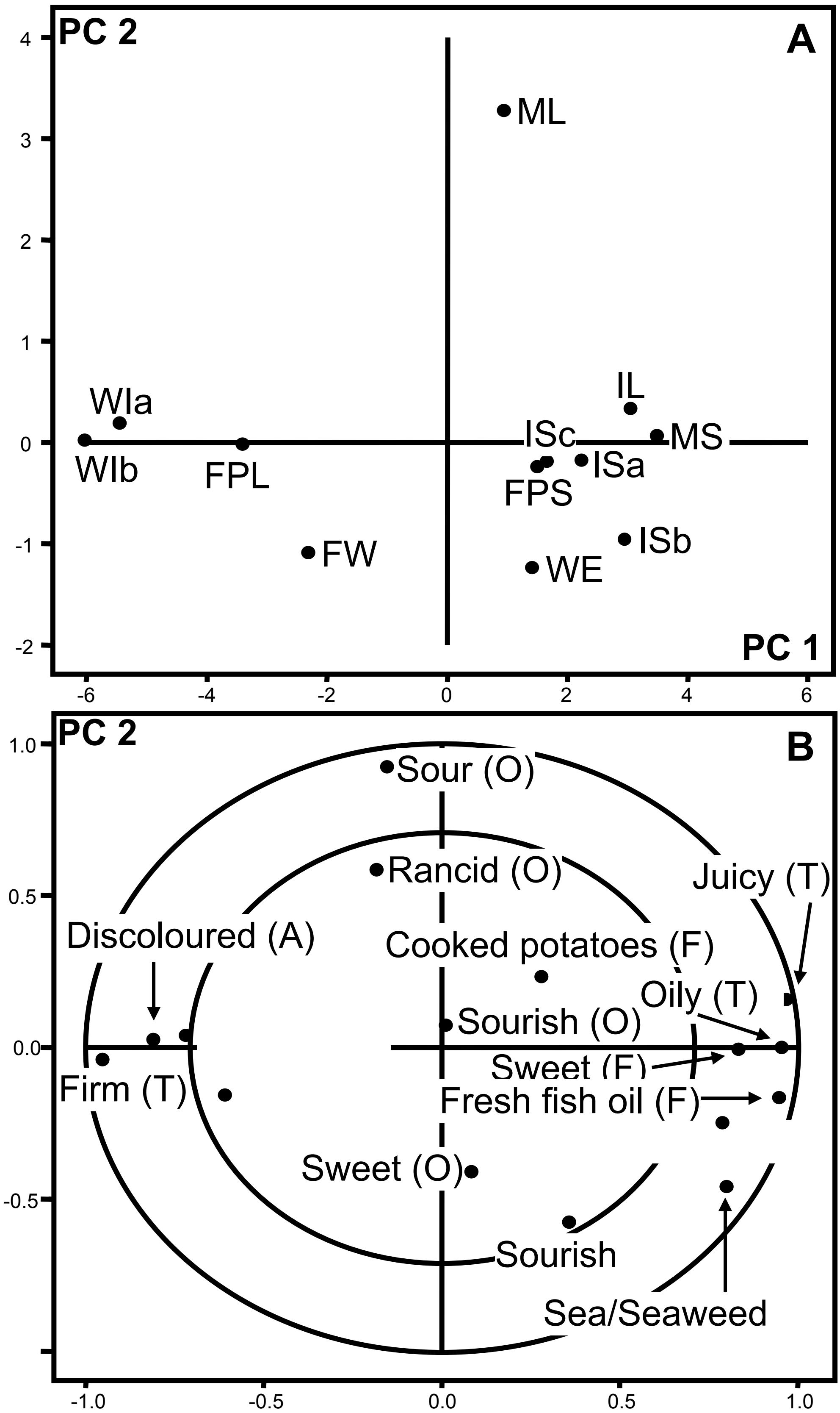

Figure 3.1: Scores (A) and correlation loadings (B) from a PCA model of the sensory profiling of salmon samples on the Danish market (Experiment 1 - Paper I). The descriptor salmon colour (A) was not included in the model. PC1 and PC2 explain 73% and 8% of the total variance, respectively. The score value labels refer to the samples listed in Table 2.1.

The four samples stored in ice were much more similar in the sensory profile than the frozen samples. All of the ice storage samples had a high PC1 score (Figure 3.1), and ice storage was correlated with the descriptors sea/seaweed odour, juicy and oily texture, fresh fish oil, sweet and mushroom flavour, and negatively correlated with firm texture, rancid flavour and discoloured appearance. Even though the ice storage samples represented different fish farms, different batches (Table 2.1) and different storage times in ice (7 or 16 days), no clear sensory differences were observed. This is in agreement with Sveinsdottir et al. (2002) who found that the most obvious changes in flavour of ice-stored Atlantic salmon happen after 17-19 days. Sveinsdottir et al. (2003) found that Atlantic salmon becomes less firm and juicy during ice storage. However in the present study, no clear difference was observed in either juiciness or firmness between the two different storage times in ice (7 and 16 days).

The two samples stored in MA had rather different sensory profiles. Sample MS (Atlantic salmon MA packed and stored for 5 days), WE (wild Chum salmon, stored frozen), FPS (Atlantic salmon, frozen for 1 month) and the samples stored in ice had a relatively similar sensory profile. Sample ML (Atlantic salmon, MA packed and stored for 7 days), on the other hand, was rather different from the rest of the samples, although it had only been stored for 2 days more in MA than sample MS (Table 2.1). ML was the sample with the highest PC2 score (Figure 3.1). A high PC2 score was correlated with rancid and sour odour, and negatively correlated with sourish flavour and sweet odour. ML also had a lower PC1 value than MS. The reason for this is that ML had a lower intensity of sea/seaweed odour, juicy and oily texture, fresh fish oil and mushroom flavour, and a higher intensity of rancid flavour, than MS. The sensory differences between MS and ML were not as marked as the sensory difference between some of the frozen samples but they were still apparent. The difference between MS and ML may exist because of the difference in storage time, but differences in raw material might also be of importance. However samples ISa, ISb and ISc, which had all been treated the same way but are from different batches, were much more alike than MS and ML. This indicates that the difference between MS and ML is not only caused by batch variation. Another factor which might influence the results is that there can be variation between individual fish from the same aquiculture batch (Paper III and Section 3.4), and only a limited amount of samples from each code (two samples for each assessor) was included in the experiment.

3.3 Objective sensory quality, consumer preferences and descriptions

Consumer preferences of salmon products in relation to sensory profiles obtained with a sensory panel and consumers' descriptions of products were studied in Experiment 2 (Paper II).

3.3.2 Consumer preference of salmon

The products from Atlantic salmon (IL, IS, FS, FL, MS and ML) had the highest average preference score, followed by Coho salmon (WI) and Chum Salmon (WE) (Table 3.2). The sample codes are explained in Table 2.2. The overall liking scores for the samples of Atlantic salmon with a long storage time were all lower than the overall liking scores for samples with a short storage time with the same treatment, and there was a significant effect of short and long storage time on the Atlantic salmon samples. The samples with long storage time are ML (packed in MA and stored for 8 days), IL (stored in ice for 15 days) and FL (stored frozen for 5 months), while samples with short storage time are MS (packed in modified atmosphere and stored for 6 days), IS (stored in ice for 8 days) and FS (stored frozen for 1.5 months). The average liking score and standard deviation for all samples of Atlantic salmon with a long and short storage time were 6.3 ± 2.0 and 6.6 ± 1.8 respectively. No significant connection was found between consumers' liking scores and self reported consumption of fish in general and different types of salmon products.

Table 3.2: Average liking scores for each salmon product for each country and for all consumers. The letters in the column with all consumers indicates significant differences between samples, while the letters in the columns for each country indicate significant differences between the countries for each sample. Sample codes are explained in Table 2.2.

Liking scores	Iceland	Denmark	Ireland	The Netherlands	All consumers
IL	6.8 ± 1.6^{a}	5.8 ± 2.1^{b}	5.8 ± 2.2^{b}	6.5 ± 2.4^{ab}	6.2 ± 2.1^{a}
IS	6.7 ± 1.7	6.7 ± 1.6	6.6 ± 1.5	6.1 ± 2.3	6.6 ± 1.7^{a}
FL	6.1 ± 2.0	6.5 ± 1.9	6.5 ± 2.0	6.3 ± 2.2	6.4 ± 1.9^{a}
FS	6.5 ± 1.7	6.5 ± 1.6	6.9 ± 1.7	6.2 ± 2.3	6.6 ± 1.8^{a}
WE	4.1 ± 1.6^{b}	5.1 ± 2.0^{a}	4.4 ± 2.0^{ab}	4.7 ± 2.6^{ab}	4.6 ± 2.0^{c}
WI	5.1 ± 1.7^{b}	6.1 ± 1.8^{a}	5.2 ± 2.0^{b}	5.5 ± 2.4^{ab}	5.5 ± 1.9^{b}
ML	6.6 ± 1.7	6.2 ± 2.0	6.2 ± 2.0	6.1 ± 2.5	6.3 ± 2.0^{a}
MS	6.8 ± 1.6	6.4 ± 1.9	6.6 ± 1.7	6.5 ± 2.3	6.6 ± 1.8^{a}

For the products IL (Atlantic salmon stored in ice for 15 days), WE (Chum salmon stored frozen for 9 months) and WI (Coho salmon stored frozen for 8 months) there was a significant difference between the consumers from the different countries. For the rest of the samples, no significant effect of different countries was found. The preference of consumers from The

Netherlands was not significantly different from that of any of the other countries. A factor that might be important in relation to this finding is that approximately half as many consumers completed the consumer test in The Netherlands than in the other countries (Paper II).

For sample IL (Atlantic salmon stored in ice for 15 days), a significantly higher liking score was found in Iceland than in Denmark and Ireland. The Icelandic consumers seemed to a very high extent to agree on liking sample IL, whereas both the consumers from Denmark and Ireland were more diverse in their liking of sample IL. The liking score for sample WI (Coho salmon stored frozen for 8 months) was significantly higher in Denmark than in both Iceland and Ireland. Furthermore, the liking of sample WE (Chum salmon stored frozen for 9 months) were significantly higher in Denmark than in Iceland. For sample WE, the consumers from Denmark seemed to be split into two groups, almost identical in size, based on the liking score of sample WE (51% of the Danish consumers gave a liking lower than 5). This was not the case for the consumers from Iceland who were in much more agreement in disliking sample WE (82% of the Icelandic consumers gave a liking score lower than 5). Sveinsdóttir et al (2009) have comparably found that there can be differences between consumers from different countries in liking cod products. Similarly, others have found differences between consumer preference in different countries of other food types (e.g. Heidema and De Jong, 1997; Prescott et al., 2001).

3.3.2.1 Cluster analysis

Three clusters were identified based on the liking scores (Table 3.3):

- Cluster 1 gave low liking scores to sample FL (Atlantic salmon stored frozen for 5 months), WE (Chum salmon stored frozen for 9 months) and WI (Coho salmon stored frozen for 8 months). None of the other clusters gave low liking scores to sample FL. Cluster 1 also gave relatively low liking scores to the samples which had been stored in MA (MS and ML), but high liking scores to sample IL (Atlantic salmon stored in ice for 15 days).
- Cluster 2 was the cluster with most consumers and it had many similarities with the overall results. However the sample gave sample FS (stored frozen for 1.5 months) a remarkably low liking score.
- Cluster 3 gave high liking scores to sample WI (Coho salmon stored frozen for 8 months). The liking score of sample WI in cluster 3 was not significantly different from sample FL

(Atlantic salmon stored frozen for 5 months), MS (packed in modified atmosphere and stored for 6 days), FS (Atlantic salmon stored frozen for 1 month), and IS (stored in ice in 8 days). Furthermore the consumers in cluster 3 disliked sample IL (Atlantic salmon stored in ice for 15 days), as they gave a significantly lower liking score to IL than to all the other samples.

Table 3.3: Number of consumers and average liking score and standard deviation for each product in each of the three clusters. The letters indicate significant differences between the clusters for each sample (only the rows with liking score).

Sample	Cluster 1	Cluster 2	Cluster 3
Number of consumers	116 (31%)	153 (40%)	112 (29%)
Country			
Iceland	42 (36%)	66 (43%)	13 (12%)
Denmark	23 (20%)	27 (18%)	52 (46%)
Ireland	31 (27%)	46 (30%)	32 (29%)
The Netherlands	20 (17%)	14 (9%)	15 (13%)
Age			
18-29	33 (28%)	47 (31%)	34 (30%)
30-39	18 (16%)	24 (16%)	15 (13%)
40-49	14 (12%)	33 (21%)	14 (13%)
50-59	19 (16%)	21 (14%)	8 (7%)
60-69	18 (16%)	20 (13%)	30 (27%)
70-79	12 (10%)	8 (5%)	8 (7%)
80-89	2 (2%)	0 (0%)	3 (3%)
Liking scores			
IL	6.8 ± 1.7^{a}	7.0 ± 1.5^{a}	4.6 ± 2.1^{b}
IS	6.4 ± 1.9	6.8 ± 1.6	6.5 ± 1.7
FL	5.1 ± 2.1^{b}	6.8 ± 1.7^{a}	7.0 ± 1.7^{a}
FS	6.9 ± 1.8^{a}	6.2 ± 1.8^{b}	6.8 ± 1.7^{a}
WE	5.4 ± 1.7^{a}	3.1 ± 1.3^{b}	5.6 ± 2.1^{a}
WI	5.3 ± 1.9^{b}	4.9 ± 1.9^{b}	6.5 ± 1.6^{a}
ML	6.2 ± 1.9	6.7 ± 1.9	5.9 ± 2.1
MS	6.0 ± 2.0^{b}	7.0 ± 1.5^{a}	6.8 ± 1.7^{a}

No significant differences were found between the three clusters based on gender and consumption of fish as main course. However a significant effect was found based on country and age (Table 3.3). The effect of country and age was mainly based on the difference between consumers from Iceland and Denmark. Most consumers from Iceland were in clusters 1 and 2, while more than half of the consumers from Denmark were in cluster 3. Cluster 3 gave low liking scores to sample IL and high liking scores to sample WI compared to clusters 1 and 2, as the Danish consumers generally also did. Furthermore cluster 3 had many consumers in the age group between 60-69 years old (27%), the reason for this is that many of the Danish consumers were in this age group (26%) (Paper II). Cluster 3 also had few consumers aged between 40-49 years old (13%), while cluster 2 had many consumers between 40-49 years old (21%), but few consumers between 60-69 years old (13%). There are especially many consumers from Iceland that belong to the age group 40-49 years old in cluster 2. 90% of the consumers from Iceland in this age group were in cluster 2 (Paper II). Therefore the significant effect of age is most likely connected to the difference between countries. It would have been an advantage if the distribution in relation to age of the consumers had been more similar in the different countries. However, during the planning of the experiment it was decided not to define other demands to consumers' age than that they should be over 18 years, since additional demands would make it more difficult to recruit the required number of consumers.

3.3.3 Comparison of objective sensory profiles and consumer descriptions

Descriptions of products in the consumer test were obtained by sensory profiling, and also by analyzing consumers' comments on products in the open-ended question. The analysis of the consumer comments showed that there were significant differences between the samples for 18 comments (Table 3.4). Nine out of the 18 comments, which were significantly different, were related to the texture of the samples, while only one was related to the odour. This suggests either that the texture of salmon was a very important factor for the liking of the product, or that there were considerable differences in the texture of the sample and/or that the texture was easier to describe for the consumers.

Table 3.4: Comments which are mentioned at least 40 times in total for all eight samples (see Paper II for details about data analysis). The numbers show how many times each comment was mentioned for each sample. The table also shows the significant level (*p* values) for each comment. Samples with a *p* value higher than 0.05 were not significant (NS).

Comments	WE	WI	FL	FS	IL	IS	ML	MS	P value
Appearnace									
Light colour	31	2	11	10	7	6	11	9	< 0.0001
Pink	14	25	7	2	3	2	3	5	< 0.0001
Proteins[1]	4	8	6	5	7	9	8	9	NS
Flaky	4	9	7	3	2	2	8	5	NS
Good	13	28	31	46	36	28	24	32	0.0017
Bad	71	34	17	4	12	8	17	13	< 0.0001
Odour									
Neutral	7	9	7	13	13	8	7	4	NS
Good	16	12	20	18	13	10	18	18	NS
Bad	7	7	4	2	13	5	7	2	0.032
Flavor/Taste									
Strong	10	11	17	10	8	11	11	14	NS
Neutral	73	73	31	44	63	64	45	40	< 0.0001
Off flavour	7	6	4	6	3	4	6	6	NS
After taste	21	16	23	12	15	14	20	22	NS
Fish	6	10	8	5	3	4	3	5	NS
Good	41	60	99	98	92	98	84	95	< 0.0001
Bad	59	43	34	30	30	16	31	21	< 0.0001
Texture									
Firm	47	63	41	36	15	19	18	21	< 0.0001
Soft	0	1	6	11	28	23	30	28	< 0.0001
Juicy	2	4	12	12	13	18	16	20	0.0012
Dry	86	81	28	35	8	9	12	14	< 0.0001
Tender	2	1	9	14	31	19	22	18	< 0.0001
Tough	88	61	22	12	8	8	8	10	< 0.0001
Rubber	9	10	8	3	4	4	0	3	0.019
Good	13	23	41	53	49	47	46	26	< 0.0001
Bad	15	22	7	8	12	4	10	6	0.0016
General									
Watery	8	3	3	8	6	1	7	6	NS
Fatty	7	7	31	25	42	43	45	42	< 0.0001

[1]This refers to white stuff, egg white.

Both results from the sensory profiling and the consumers' comments were related to consumer liking using external preference mapping (Figure 3.2 and Figure 3.3 respectively). There were many similarities between the sensory profile and the comments made by the consumers. This is in agreement with the results found by Kleij and Musters (2003) and Faye et al. (2006). For instance the comment fatty was correlated with oily texture from the sensory profile. There is also a clearer agreement between the consumers' use of the comment firm (and soft) with firm from the sensory profiling. This is also the case for the comment dry (and juicy) together with juicy from the sensory profiling. However there is one exception to these similarities in firm (and soft) and dry (and juicy) which is related to sample MS. In the sensory profile sample MS was found to be firm and dry, but this was not reflected in the consumers´ comments. Additionally sample FS and FL had many comments indicating that the samples were more firm/less soft than the rest of the samples made of Atlantic salmon, and this was not found in the sensory profiling. This is in agreement with results from other studies showing that texture gets more firm and less juicy during frozen storage than storage in ice (Farmer et al., 2000; Refsgaard et al., 1998; Waagbø et al., 1993). The reason for the differences in sensory profiling and the comments on juicy (and dry) and firm (and soft) might be due to the differences between the individual fish used to prepare the samples (which would be in agreement with results from Paper III and Section 3.4). Since only a small number of fish was tested in the sensory profiling, this biological variation could have more influence on the results from the sensory profiling than consumer comments.

The samples which were found to be discoloured in the sensory profile were described by the consumers as having a bad appearance. The consumer comments neutral and bad flavour were mostly used on samples which in the sensory profile were found to have a rather high intensity of rancid flavour combined with a low intensity of fresh fish oily, sourish, mushroom and cooked potato flavour. Similarly, the consumer comment bad odour is correlated with rancid and sour odour from the sensory profile. Furthermore not all the sensory attributes mentioned in the consumers´ comments (tender, tough and rubber) were covered by the descriptors used in the sensory profiling.

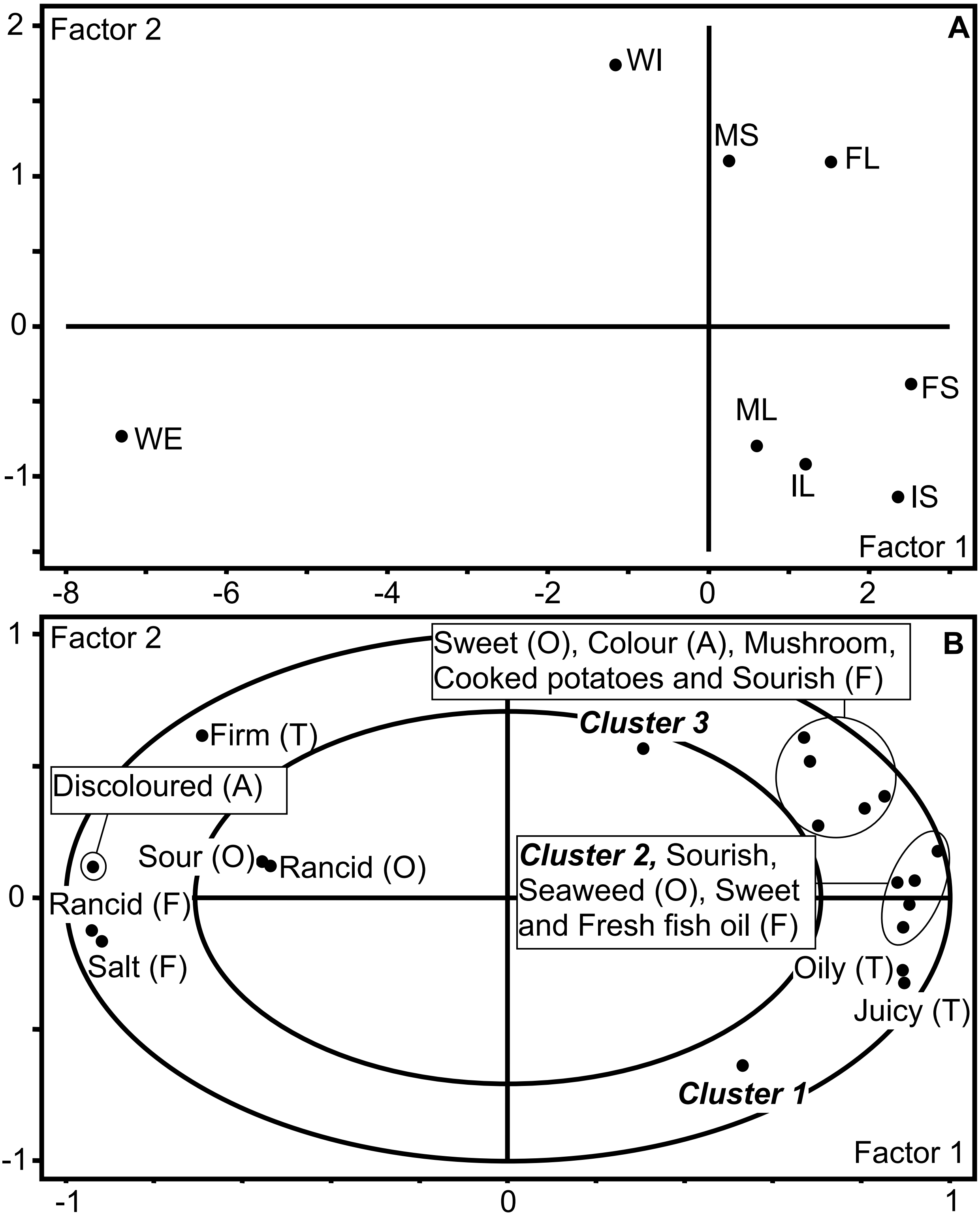

Figure 3.2: External preference map with sensory profiles. PLS model with the sensory profile as X and the average liking scores for each cluster as Y. A) Scores and B) X and Y correlation loadings from the first and second PLS factor, which explains 70% and 11% of the variation in X plus 58% and 13% of the variation in Y. A, O, F and T are appearance, odour, flavour and texture respectively. The sample codes are explained in Table 2.2 and sensory descriptors are defined in Table 2.3.

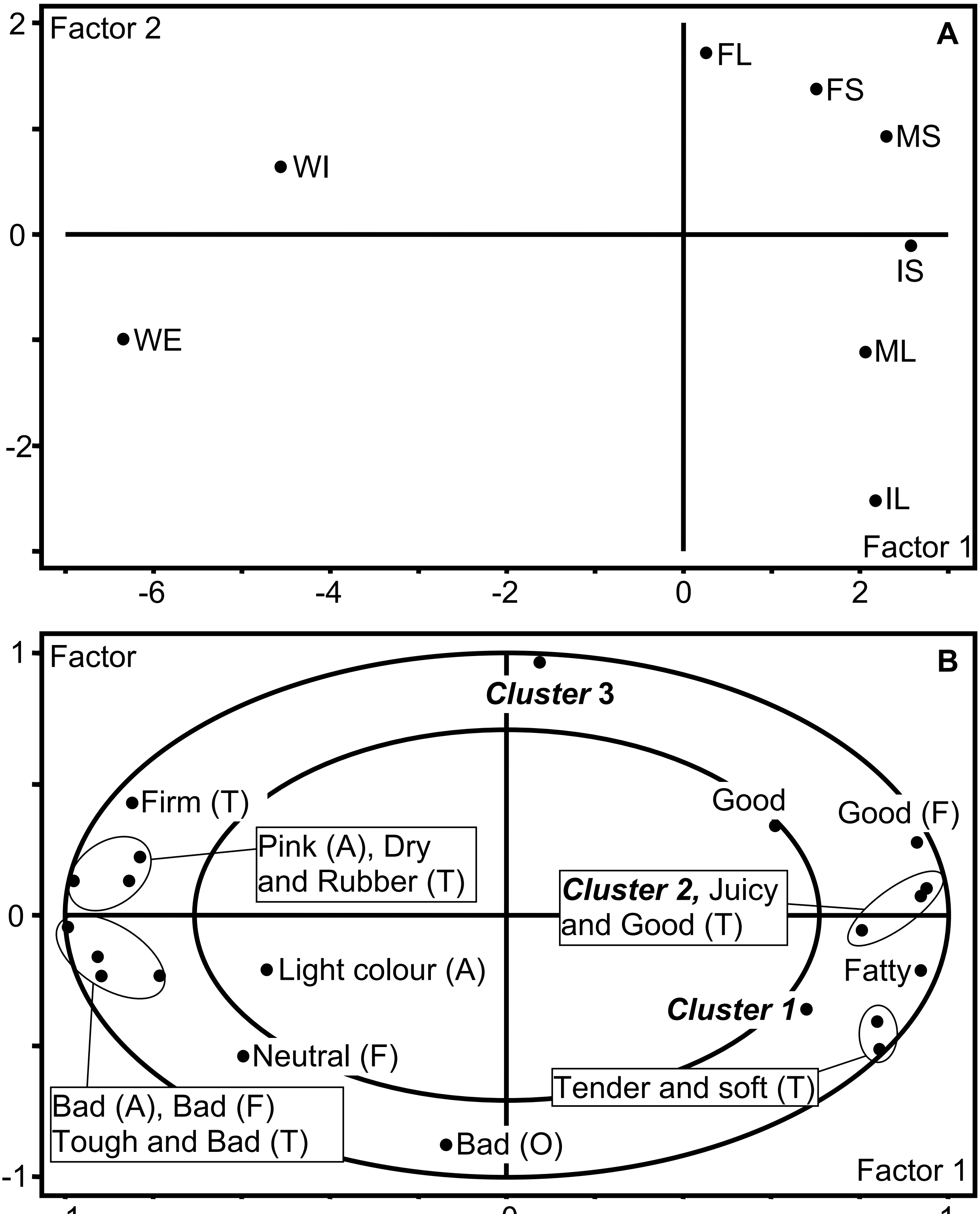

Figure 3.3: External preference map with consumer descriptions. PLS model with the consumer descriptions as X and average liking scores for each cluster as Y. A) Scores and B) X and Y correlation loadings from the first and second PLS factor, which explains 67% and 12% of the variation in X, plus 64% and 22% of the variation in Y. A, O, F and T are appearance, odour, flavour and texture respectively. The sample codes are explained in Table 2.2.

3.3.4 Connection between sensory profiles and consumer preference

The consumers generally gave lowest liking scores to sample WE (Chum salmon stored frozen for 9 months) followed by sample WI (Coho salmon stored frozen for 8 months) (Table 3.2). In both the sensory profiling and the consumer comments sample WE, followed by sample WI was described as having a considerably lower sensory quality than the samples of Atlantic salmon (Figure 3.2 and Figure 3.3). In the sensory profiling, sample WE had a high intensity of sour and rancid odour, salt and rancid flavour, discoloured appearance and firm texture, combined with a low intensity of sweet and sourish odour, sea/seaweed, fresh fish oil, cooked potatoes, mushroom, sweet and sourish flavour, oily and juicy texture and colour appearance in the sensory profiling. Sample WI had many of the same sensory characteristic but not as pronounced as sample WE (Figure 3.2). The consumers characterized samples WI and WE by using comments such as bad appearance, neutral and bad flavour/taste, bad, tough, dry, rubber and firm texture. However in the consumer comments sample WI was also more positively described than sample WE (Figure 3.3 and Table 3.4). In the consumer comments sample made of Atlantic salmon on the other hand, the fish was described as fatty and having good flavour, soft, juicy, tender and good texture and consumers gave these samples high liking scores (Figure 3.3 and Paper II). Therefore both the sensory profiling and consumer comments reflect the consumers overall liking of the products.

The reason that the samples of Chum and Coho salmon (WE and WI) were so different from the samples of Atlantic salmon might be differences between the species and origin (farmed and wild), however the prolonged frozen storage and possibly other differences in treatment of WE and WI (Table 2.2) are likely to have significant influence. Since in Experiment 1 (Paper I) it was found that the samples of Chum salmon were not particularly different from the samples of Atlantic salmon, while the samples of Coho salmon showed a bigger difference to the Atlantic salmon. That freezing can be of importance is confirmed in several other studies (Farmer et al., 2000; Refsgaard et al., 1998; Waagbø et al., 1993).

The second PLS factor in the external preference mapping with both the sensory profiling (Figure 3.2) and consumer comments (Figure 3.3) is related to the differences between cluster 1 and 3. Consumers in cluster 1 liked sample IL (Atlantic salmon stored in ice for 15 days), but disliked sample FL (Atlantic salmon stored frozen for 5 months), WI (Coho salmon stored frozen for 8 months) and MS (packed in MA and stored for 6 days) compared to consumers in cluster 3 (Table 3.3). The main differences in the sensory profiling found between samples IL and FL were that sample FL had high intensity of salmon colour, cooked potatoes, sourish and mushroom flavour.

Furthermore sample IL together with sample ML (packed in MA and stored for 8 days) were correlated with the consumer description bad odour. This suggests that the quality of these two samples had been decreasing due to storage time and furthermore that at least some of the consumers recognized this quality change. Samples FL and FS (Atlantic salmon stored frozen for 5 and 1 months respectively) on the other hand, were more frequently described as having a firm and dry texture, but not as frequently as samples WE and WI. In contrast to samples FL and FS, the other samples of Atlantic salmon (IL, IS, ML and MS) were more often described by the consumers described as fatty, soft and tender. The consumers in cluster 3 did not like the samples which had a bad odour but appeared to like the samples which were firm and dry, however not as dry and firm as sample WE. On the other hand the consumers in cluster 1 appear to prefer samples where the odour and flavour profile has decreased in quality over samples was which are firm and dry.

The samples of Atlantic salmon with a long storage period (FL, IL and ML) compared to samples with a short period (FS, IS and MS) had higher intensity of the sensory descriptors sour odour, rancid odour and flavour combined with a low intensity for fresh fish oil flavour and oily texture. Also samples ML and IL were, by the consumers, more often described as having a bad odour. This probably explains the lower liking scores for the samples with long storage time compared to those with a short storage time. The sensory characteristics of ice-stored Atlantic salmon do not change much during the first two weeks of storage (Sveinsdottir et al., 2002; Sveinsdottir et al., 2003; Paper I). However, at the end of shelf-life, sour, rancid, amine and musty odour, sour, amine and rancid flavour and discolouration are evident (Sveinsdottir et al., 2002; Sveinsdóttir et al. 2003).

3.4 Variation between fish within a batch

Part of the objective with Experiment 4 was to answer the following question: How much variation is there in sensory quality of fish from the same aquaculture product batch? The experiment included both a comparison of individual fish taken out of a production line at the same time (Section 3.4.1), and a comparison of groups from the same batch taken out of a production line at different times during a production day (Section 3.4.2).

3.4.1 Comparison of individuals within the groups

In all three groups significant differences were found between at least two individual fish on at least two sensory descriptors from the sensory profiling (Table 3.5 - for further details see Paper III). Overall the results therefore confirm that there can be significant differences in sensory characteristics of heat-treated individual trout belonging to the same production batch.

Within group X significant differences were found for the sensory descriptors firm, juicy and cooked potato flavour. In relation to the texture, one fish was especially notable since it was the most firm and least juicy fish in the experiment. Both in relation to firm and juicy texture this fish was significantly different from two of the other fish in group X. This sample also had a rather special chemical composition since the fish within group X had the highest lipid content and the lowest water content (Paper IV). Additionally a significant ($p=0.006$) negative correlation ($r = -0.49$) was found between the sensory descriptor firm and the lipid content (all 30 fish in the experiment were used in the calculation). This is in agreement with the results for smoked and cooked Atlantic salmon (*Salmo salar*) found by Robb et al. (2002). Also in the sensory descriptor cooked potato flavour a significant difference was found between two samples within group X.

In group Y the sensory descriptors sweet odour, sour flavour and fresh fish oily flavour significantly separated at least two samples (Table 3.5). Especially one fish was notable since this fish was sweet, less sour and had a high intensity of fresh fish oily (Paper III). In group Z differences were found in relation to the sensory descriptors wet dog odour and sour flavour (Table 3.5). The differences found between the individual fish in each group could not be explained by the other measurements performed, though differences in pH, lipid and water content were observed between several of the individual fish (Paper III).

Differences in mechanically measured texture on raw fillets were found between individual fish in both groups X and Z (Table 3.5). In group X there were significant differences between two individual fish, while in group Z, two fish had a significantly lower max compression force than one other fish (Paper III). It was not possible from the results of the chemical measurement to give clear explanations for these differences. No observed differences in QI were found between the individual fish in the three groups (Table 3.4).

Table 3.5: Results from comparison of individual fish within groups X, Y and Z, together with results from the comparison between the groups (Group differences). The table shows p-values from one-way analysis of variance (ANOVA)[1] for each sensory descriptor from the sensory profiling, QI scores from the QIM evaluations, length, weight, condition factor, pH, lipid content, water content and max compression force from the mechanical texture measurement. p-values higher than 0.05 were considered Not Significant (NS).

	Group X	Group Y	Group Z	Group differences
Sensory profiling				
Odour				
Sweet O	NS	0.0004	NS	0.0018
Cooked potatoes O	NS	NS	NS	0.0003
Wet dog O	NS	NS	0.0407	NS
Sourish O	NS	NS	NS	NS
Warm milk O	NS	NS	NS	NS
Sickly-sweet O	NS	NS	NS	<0.0001
Texture				
Firm T	0.0062	0.0404	NS	NS
Juicy T	0.0059	NS	NS	NS
Oily T	NS	NS	NS	NS
Flavour				
Sweet F	NS	NS	NS	0.0030
Fresh Fish oily F	NS	0.0201	NS	NS
Mushroom F	NS	NS	NS	<0.0001
Sourish F	NS	NS	NS	NS
Cooked potatoes F	0.0431	NS	NS	NS
Sour F	NS	0.0036	0.0029	NS
QI	NS	NS	NS	NS
Length (cm)	-	-	-	NS
Weight (g)	-	-	-	0.0323
Condition factor	-	-	-	NS
pH	<0.0001	<0.0001	<0.0001	NS
Lipid (%)	<0.0001	0.0052	<0,0001	0.0123
Water (%)	<0.0001	0.0048	NS	0.0215
Texture (g)	0.0106	0.0018	0.0039	0.0147

[1] For the mechanical texture measurements a nonparametric, the Kruskal-Wallis test was used

3.4.2 Comparison between groups

The results from the sensory profiling showed significant variations between the three groups. For 5 of the 15 sensory descriptors significant differences between two of the three groups were found. The significant descriptors include the odour descriptors sweet, cooked potatoes and sickly-sweet and the flavour descriptors mushroom and sweet (Table 3.5). Groups X and Z were the most different since there were significant differences in all five significant descriptors. Group Y is significantly different from group X only in the descriptors cooked potatoes and sickly-sweet odour. Furthermore group Y is significantly different from group Z in the descriptors mushroom and sweet flavour (Paper III). The chemical and physical measurements did not give any explanation for the considerable difference between group X and Z, although the two groups differed in the mechanical texture measurement. While group Z had a higher max compression force on the raw fillet than group X. Groups X and Y were, however, most different when comparing the chemical and physical measurements. The fish in group X generally had a higher weight (3468g compared to 3208g), higher water content (70.9% compared to 69.4%) and lower lipid (9.3% compared to 11.5%) content than the fish in group Y. No observed difference in QI was found between the three groups.

3.5 Communication of sensory quality in the seafood production chain

Sensory evaluations are as described in the introduction (Section 1.1.3) used in many of the steps in the seafood processing chain. However the evaluations are generally not performed in the most optimal way. A considerable problem is that there is generally no communication of demands to sensory quality and results from sensory evaluations between the different partners in the chain (Martinsdóttir et al., 2008). Therefore a Seafood Sensory Quality Model (SSQM), which can be used for communicating sensory quality by the partners in seafood production chain, is suggested.

To understand the SSQM it is necessary to understand which sensory methods are relevant to use in the seafood production chain, and describe in some detail where and how the methods can be used in the different steps in the chain (Section 3.5.1). It is also necessary to understand the importance of communicating sensory quality in the seafood production chain (Section 3.5.2). The SSQM will be described in Section 3.5.3. Additional experiments (Experiment 3 and part of Experiment 4) were performed to illustrate the value of communicating and relating sensory quality in different parts of the seafood processing chain. In Experiment 3 a real seafood production chain was followed (Section 3.5.4), while a simulation of a seafood production chain was performed in Experiment 4 (Section 3.5.5).

3.5.1 Sensory evaluation in the seafood production chain

The choice of sensory method depends on a number of different factors, including the reason for performing the sensory evaluations. An overview of important factors of relevance for the sensory evaluations in the seafood processing chain can be seen in Table 3.6. The table includes references to Figure 3.4 which shows an example for a typical seafood processing chain, including suggestions for where it can be relevant to perform sensory evaluations (test points).

The sensory evaluations can be performed as visual inspection, measurement of odour, texture and taste. Visual inspection can be performed on whole fish and raw or heat-treated fillets. Changes in freshness influence the appearance of fish and visual inspection can therefore be part of freshness evaluation. Visual inspection can also be used to detect other characteristics such as fish species, physical damage and the presence of some diseases in the fish. Physical damage can cause a fast reduction in shelf-life. Furthermore, it can influence the appearance of the final product (Hyldig et al., 2007). Another purpose of visual inspection can be to check the product for foreign matter not wanted in the product. This can be e.g. sand, seaweed, packing material, bones or parasites. Also, the quality of washing, packing, gutting, bleeding and filleting as well as the amount of ice packed with fish can be inspected with visual tests. Additionally, flesh colour, gaping and homogeneity of the flesh can be tested with visual inspection of both raw and cooked fish. In total there are many different objects of visual testing that are relevant for inspection in the seafood processing chain. Visual inspection can be relevant to perform in all the test points showed in Figure 3.4.

Table 3.6: Important factors relevant to measuring with sensory methods in the seafood processing chain

Purpose	Test point from Figure 3.4[1]
Freshness	3, 4, 7, 9 and 10
Species	1,3 and 4
Physical damage of the fish	1, 3 and 4
Fish illness	1, 3 and 4
Presence of foreign matter	2, 3, 4, 6, 7, 9 and 10
Presence of parasites	5, 6 and 7
Presence of bones	6, 7, 9 and 10
Amount of ice	2, 3 and 4
Quality of bleeding	2, 3 and 4
Quality of gutting	2, 3 and 4
Quality of washing	2, 3 and 4
Quality of parking	4, 6, 7, 9 and 10
Quality of filleting	6 and 7
Presence of gaping	5, 6 and 7
Colour and homogeneous	5, 6, 7, 9 and 10
General appearance	7, 9 and 10
Presence of off-odours	7, 9 and 10
General odour	7, 9 and 10
Texture	4, 7, 9 and 10
Taste	7, 9 and 10
Quality of other ingredients	8

[1]Shows references to where the different sensory test purposes can be relevant in the example of a seafood processing chain from Figure 3.4.

Another type of sensory assessment is evaluation of odour, which again can be performed on both raw and heat-treated samples, while evaluation of taste is done on heat treated-products or products preserved in another way such as sushi and marinated fish. In the seafood industry, sensory tests of the taste are normally performed on a company's final product (Martinsdóttir et al., 2008). Odour and taste evaluation of seafood can be made as part of a freshness evaluation, for instance by checking for the presence of rancid odour and flavour. Odour and taste evaluations can also be performed to check off-flavours e.g. muddy or earthy odours (Howgate, 2004) or spices in manufactured products.

Texture can also be measured on both raw and cooked samples, and texture evaluations can be part of a freshness evaluation, since, for example, firmness of the fish flesh is reduced during storage in ice (Sveinsdottir et. al, 2002). Other aspects of texture which can be of interest are juiciness and toughness of cooked fillets.

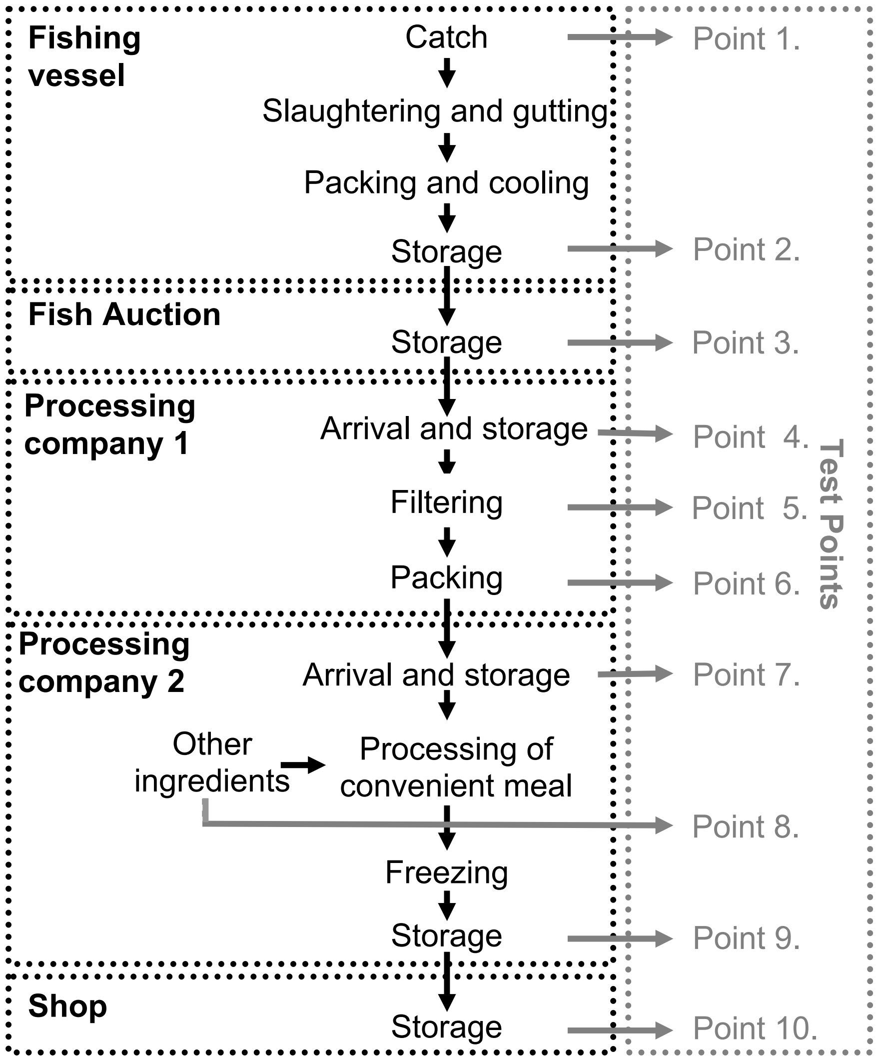

Figure 3.4: Example of a realistic fish processing chain including suggestions of sensory quality test points. Steps relating to transport between the different companies in the processing chain are not shown.

Different sensory methods can be used in the sensory evaluations. It is important that the methods used have sufficient precision in measuring a given characteristic (Costell, 2002). Additionally, the methods usually need to be fast both in performance and in the subsequent data analysis. The most suitable methods are generally descriptive tests and quality ratings, which make it possible to measure the degree of the variation between the product and the demands to sensory quality. In some cases in/out methods can be recommended (Munoz et al., 1992).

In descriptive tests, the intensity of a single sensory parameter is evaluated on a scale (Lawless and Heymann, 1998). The result from the descriptive tests needs to be translated into different quality levels. The main advantages of using descriptive tests in a production chain are that the result gives a complete picture of the characteristics and their intensity. The disadvantages of descriptive tests are that they are relatively time demanding in training of the assessors and in data treatment (Munoz et al., 1992).

In quality rating, characteristics are also evaluated on scales. However, these scales are quality scales with end points such as "very poor quality" and "excellent quality". Quality rating has some disadvantages compared to descriptive tests, as descriptive tests give the intensity of every single attribute. This means that more detailed data can be established from descriptive tests. Additionally, quality rating also demands a longer training program for the assessors compared to descriptive tests (Munoz et al., 1992), since it is important that the assessors understand the different quality levels.

Descriptive tests and quality rating can both be used for many different purposes in relation to the seafood processing chain. This includes determination of freshness, appearance (including colour and homogeneity), odour (including off-odours), taste and texture (Table 3.6). Descriptive test and quality rating are therefore relevant methods in most of the test point shown in Figure 3.4 (test point 2 to 4 and 6 to 10).

When using in/out methods the assessors decide whether the product is within or outside a given standard. Assessors need also here to be trained in using the standards; however, the training is not as extensive as for descriptive methods. Another advantage is that the results are known instantly. In/out methods can be used if a simple classification of the samples is satisfactory (Munoz et al., 1992). In/out methods are especially relevant in relation to on-line evaluations (test points 1 and 5 in Figure 3.4). For instance in/out methods can be used in evaluation of appearance, physical damage, fish diseases, unwanted substances, parasites, bones, amount of ice in the box, gaping, and quality of gutting, washing, packing and filleting.

As described above, measurement of fish freshness is important in the seafood processing chain. In the example from Figure 3.4 it is relevant to measure freshness at test points 3, 4, 7, 9 and 10. Specific sensory methods including the EU scheme (Anonymous, 1996), Quality Index Method

(QIM) (Bremner, 1985; Hyldig and Green-Petersen 2004) and the Torry scale (Howgate et al., 1992) have been developed to evaluate freshness of fish.

The value of the SSQM depends on the reliability of the sensory evaluation performed in each step of the seafood processing chain. Demands to sensory quality need to be defined, the most appropriate methods must be used in evaluations, and sensory evaluations should be performed according to guidelines for sensory tests (NMKL Procedure No 21, 2008; ISO standards 8586-1, 1993; ISO standards 8589, 1988).

3.5.2 Communication of sensory quality in the seafood processing chain

An overall problem in seafood processing, is that results from the sensory evaluations in a single step of the chain are often unavailable to the other partners in the chain. This is a setback since the results are generally not only relevant for the partner performing the evaluations, but also for the other partners. Examples demonstrating the value of sharing sensory quality information in the seafood processing chain are shown in the following.

Example 1: A company producing fish fillets

Processing company one from Figure 3.4 buys raw material (fish) from a fish auction and stores the fish until filleting and packing - the packed fillets being the end product. The company measures freshness by using the sensory evaluations of the raw material (test point 4 in Figure 3.4). The company can use the measured freshness first of all to decide if the freshness is acceptable and therefore the raw material can be used in the production. Furthermore the results can be used to determine how long the fish can be stored before production and also to establish the self-life of the company's final product. The measured freshness also gives the company documentation for the fish quality, which can be used in relation to the other partners in the chain.

For the partners earlier in the chain, the fishing vessel and the auction (Figure 3.4), the results are of high relevance because they contain information about the quality of the product from the fishing vessel and the auction, and the information can be used to optimize the handling of the fish. Furthermore the processing company can use the results to determine what they are willing to pay for the raw material.

The partners later in the chain can also benefit from the information on the results from the sensory freshness evaluation performed in test point 4, since freshness here has significant *influence on freshness later in the chain. First of all the product must have a freshness which will satisfy processing company two for their production. Secondly processing company two might use the freshness evaluation results from test point 4 to predict the shelf-life of their own products. Additionally if processing company two has the results from test point 4, they might be able to reduce the extent of sensory testing performed on their raw material and/or final product (point 7 and 9) – again this demands that a systematic model for sharing of information is used.*

As illustrated in the example, communication of sensory quality is an advantage both for the partner performing the sensory testing and for partners earlier and later in the processing chain. Moreover communication of sensory quality can be used to optimize the production in the different steps of the chain. Communication is also valuable in relation to determination of the optimal way of performing sensory evaluations. First of all, as illustrated in the example above, communication can reduce the amount of sensory evaluations to be performed. Secondly communication and relation of quality between the different test points can be used for evaluation of the relevant measurements. According to Munoz et al. (1992) there are two major factors that determine which sensory characteristics should be evaluated, 1) the sensory characteristics must show a variation, 2) the sensory characteristics must affect consumer attitude towards the product.

The following example shows how communication of sensory quality between different test points can be used to determine which sensory characteristics should be measured at the different test points.

Example 2: A company producing frozen convenience meals

Processing company two from the seafood processing chain in Figure 3.4 buys packed fillets from processing company one to produce frozen convenience meals. Processing company two might have a considerable variation in the sensory quality of the raw material (measured at test point 7). The quality can e.g. vary according to filleting quality and colour. In order to determine what sensory characteristics should be measured at test point 7, company two first needs to investigate the relationship between the quality at test points 7 and 9 by making descriptive sensory measurements at both points. If the results show that e.g. both the quality of filleting and colour at point 7 influence the appearance of the product at point 9, the company needs to find out how this variation affects the consumers. This should preferably be done by performing consumer tests, which include samples representing the different appearances caused by the variation in the quality of filleting and colour. If the consumer tests show that filleting has a considerable influence on consumer acceptability, while the variation in colour has no effect, it is clear that it would be beneficial for processing company two to define quality demands of the filleting at test point 7 and perform sensory tests here. Furthermore processing company two should inform processing company one about the demands to filleting quality and the results from the evaluations performed at test point 7.

The results from the consumer tests regarding the non-existing influence of colour on the consumer acceptability of the products, do not necessarily implicate anything about the relevance of defining sensory standards and measurement of colour at test point 7. This is due to the fact that the variation in colour might influence the consumers' confidence and thereby the reliability of the product (Stone and Sidel, 1993).

Again the sharing of information in the chain requires an accepted communication tool.

3.5.3 The Seafood Sensory Quality Model (SSQM)

To establish communication of sensory quality in the seafood processing chain, the SSQM (Figure 3.5) is suggested. The SSQM can be used to communicate the sensory quality of seafood, and make it possible to share the understanding of the sensory quality. The SSQM makes it possible to document sensory quality at different test points and to relate it to every step in the chain. Not only results from sensory evaluation, but also other information with an effect on the sensory quality can be included. Additionally the SSQM is valuable in relation to deciding which sensory characteristics should be measured at the different test points in relation to product decision and product development.

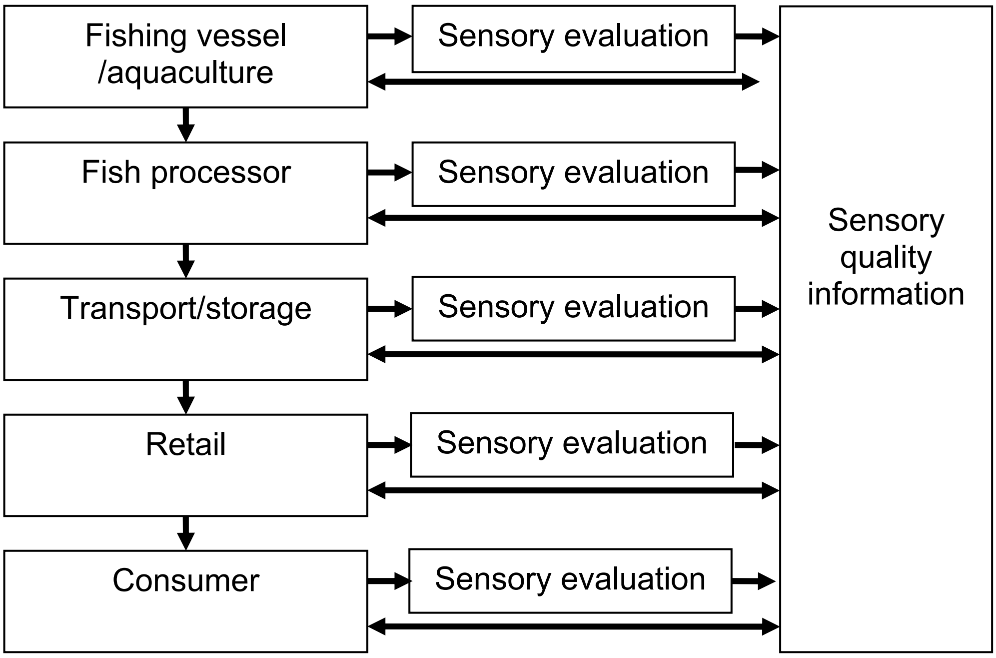

Figure 3.5: Illustration of the Seafood Sensory Quality Model (SSQM).

Figure 3.5 illustrates the SSQM with the different steps from vessel/aquaculture to consumer and show the information flow can be used for communication within the processing chain and the surrounding companies. The SSQM can be used to communicate demands and results from sensory evaluations and to communicate other characteristics which can influence the sensory quality such as microbiological, physical and biochemical characteristics (e.g. Refsgaard et al., 1998; Sveinsdottir et al., 2003, Robb et al., 2002) together with time and temperature information.

The SSQM should as far as possible be easy to use. This implies that the sensory quality information after being registered automatically must be passed on to the relevant partners in the chain. Using the internet for this information flow is an obvious possibility. The system could function in parallel with systems used for traceability.

3.5.4 Sensory quality in a real seafood production chain

Experiment 3 includes measurements performed at DTU and by the processing company, plus other information about the six batches used in the experiment (Section 2.3). Measurements performed at DTU include QIM and sensory profiling.

The six batches of farmed Atlantic salmon were all from different fish farms and slaughter houses. Additionally they all were slaughtered on different days and also used in the production at the processing company on different days. Only limited variation in temperature of both raw material (0.0 - 0.8˚C) and the finished MA packed product (-0.5 – + 1.0˚C) was observed. Similarly, only little variation was observed in colour measurement performed by the processing company (all batches had a score of 23 or 24 on Roche scale from 20 to 34 (Skrede et al., 1990)). At the end of self-life, a sensory test together with some microbiological tests were performed by the processing company. In the sensory test, which was a quality rating method, no differences were observed between the samples in either odour or flavour of cooked samples. All samples received the lowest acceptable score in both odour and flavour. These scores correspond to the description "almost no odour" and "almost no flavour" respectively. Similarly, the microbiological measurements did not show any clear differences between the batches.

The QIM measurements showed that the freshness of the raw material within batches was rather stable (Table 3.7). However one batch had a significantly higher QI score than two of the other batches. According to the information about the batches, all fish had been stored 2 to 4 days in ice before the processing. There is a linear relationship between QI and the storage time in ice. For farmed Atlantic salmon the equation is $QI = 0.692 \times D + 1{,}57$, where D is days in ice (Martinsdóttir et al., 2001). Therefore a QI score of approximately 3 to 4 was expected, but the measured QI scores were considerably higher for all batches (Table 3.7). The result indicates that, either before processing or during the transport from the processing company to DTU, the fish were exposed to higher temperatures than 0˚C.

Table 3.7: Mean Quality Index (QI) and standard deviations from the QIM evaluations on the six batches from Experiment 3.

Batch	Days from slaughtering to production	QI[1]
A	3	9.8 ± 1.5^{a}
B	3	8.7 ± 1.6^{ab}
C	2	7.6 ± 2.0^{b}
D	4	8.8 ± 0.8^{ab}
E	3	7.8 ± 1.5^{b}
F	4	8.3 ± 1.3^{ab}

[1]The QI score is corrected to the processing day by using the linear relationship between QI and the storage time in ice. For farmed Atlantic salmon the equation is QI = 0.692×D+1.57, where D is the storage time in ice (Martinsdóttir et al., 2001).

In the sensory profiling the most obvious results were that the batches, independent of storage time in MA and QI, had different sensory characteristics (not shown). Batches A and B generally had a high intensity of several flavour and odour descriptors, including sourish flavour and sweet odour. Batches E and F had a firm texture. Batches C and D were juicy, oily and had a dark salmon colour. In the colour evaluations performed by the company these batches also had a dark salmon colour compared to batches B and E, but C and D were not different from A and F. This variation in sensory characteristics was not discovered in the sensory analysis performed by the processing company.

Sensory profiling was, with one exception (one sample was evaluated after 10 days of storage in MA), performed within the self-life period of the product, which is 9 days, and none of the products in the sensory profile showed evidence that the self-life had been crossed. However the sensory characteristic did appear to change during the storage period. Both the sensory descriptor juicy texture (p=0.023) and sourish odour (p=0.009) had a significant correlation (r = 0.56 and r = 0.63 respectively) to storage time in ice. This finding was not expected, since Sivertsvik et al. (2003) have found that juiciness reduces during storage of Atlantic salmon fillets in MA. Sourish odour was also expected to decrease rather than increase during the storage period, since the definition of sourish odour is positive compared for instance to the descriptor sour (Table 2.3).

No clear effect in the sensory profiling of the differences in QI of the different batches was observed. One reason for this might have been the considerable differences in sensory profiles between each batch. If the sensory profiling had included samples which had been stored for a long period before profiling, differences in the QI of the raw material might have had an influence on the sensory profiling results. A larger variation in freshness of the batches had most likely also resulted in differences in the sensory profiling. If more batches had been included in the experiment, a larger variation in freshness of the raw material might have been found. However the results obtained indicate that this particular company has a rather stable raw material quality.

In conclusion, during the period of the experiment the quality of the raw material that the company uses was too stable to illustrate the value of relating sensory quality in the seafood processing chain.

3.5.5 Simulation of a seafood production chain

Experiment 4 included a simulation of a seafood processing chain (Figures 2.5 and 3.7), with variation in sensory quality in relation to freshness. The QIM evaluation of the Rainbow trout showed as expected an increase in the QI scores with increasing storage time on ice before freezing ($p<0.0001$). The average QI score was 5.1, 8.7 and 16.3 for 3 days, 10 days and 17 days of storage in ice, respectively. In Figure 3.6 a PLSR model of QI based on the sensory profiles is shown. QI is correlated to sour flavour, sickly sweet and wet dog odour. Furthermore QI is negatively correlated to the following odours; warm milk, sweet, sourish and cooked potatoes. Additionally QI is negatively correlated to the following flavours; fresh fish oil, mushroom, sweet, sourish and cooked potatoes. Juicy texture is also negatively correlated to QI, which is expected since both Sveinsdottir et al., (2003) and Waagbø et al. (1993) have found that juicy decreases during storage in ice. It could have been expected that firm texture would decrease due to increasing storage time in ice, since this has been reported in several other studies (Andersen et al., 1997; Azam et al., 1989; Færgemand et al., 1995; Sveinsdottir et al., 2002; Sveinsdottir et al., 2003). However this was not observed in the present study, but the present study was performed on minced Rainbow trout. Another factor which might be important is the frozen storage that all samples were exposed to after the storage in ice.

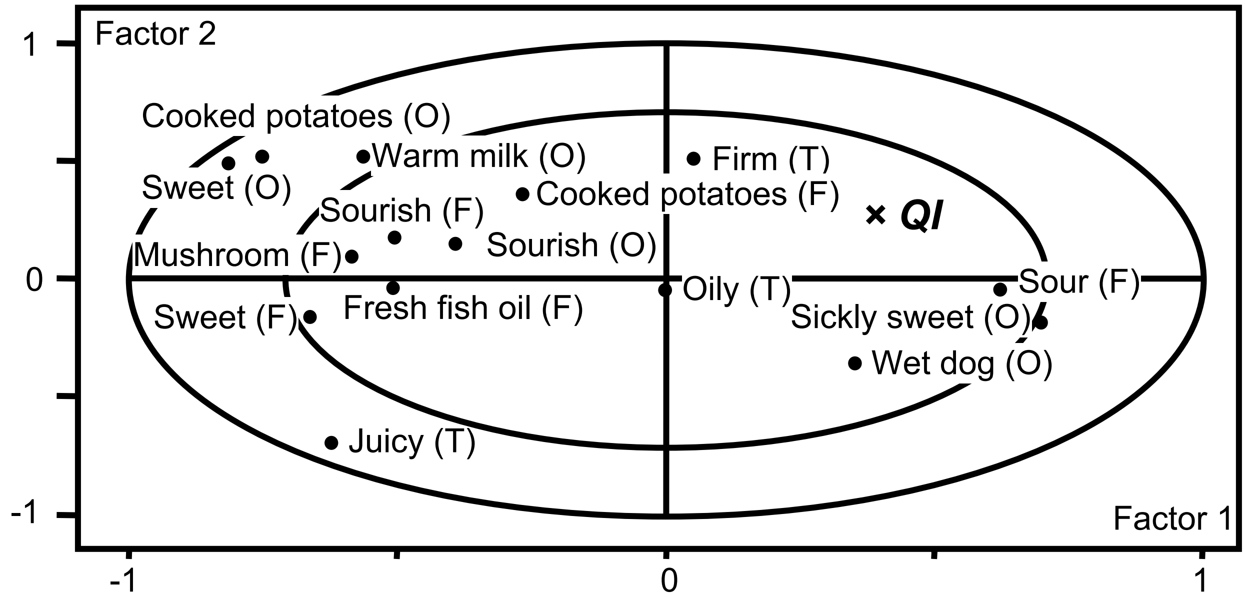

Figure 3.6: PLS1 model with the sensory profile as X and QI as Y. The Figure shows correlation loadings from the first and second PLS factor, which explains 31% and 19% of the variation in X, plus 15% and 7% of the variation in Y. A, O, F and T are appearance, odour, flavour and texture respectively. The optimal number of components was one and Root Mean Square Error of Prediction (RMSEP) was 4.5.

Overall the changes in sensory characteristics measured in the profiling were based on the findings from Experiment 2 (Paper III and Section 3.3.4) most likely to affect the consumers' preference of a hypothetical final product (consumer preference is correlated to descriptors like sourish, sweet and cooked potatoes odour, fresh fish oily, sweet, sourish, cooked potatoes and mushroom flavour). However it should be remembered that Experiment 2 was performed on Atlantic salmon while Experiment 4 was performed on Rainbow trout. Furthermore different sensory descriptors were used in the two experiments and the scales cannot be directly compared (Table 2.3).

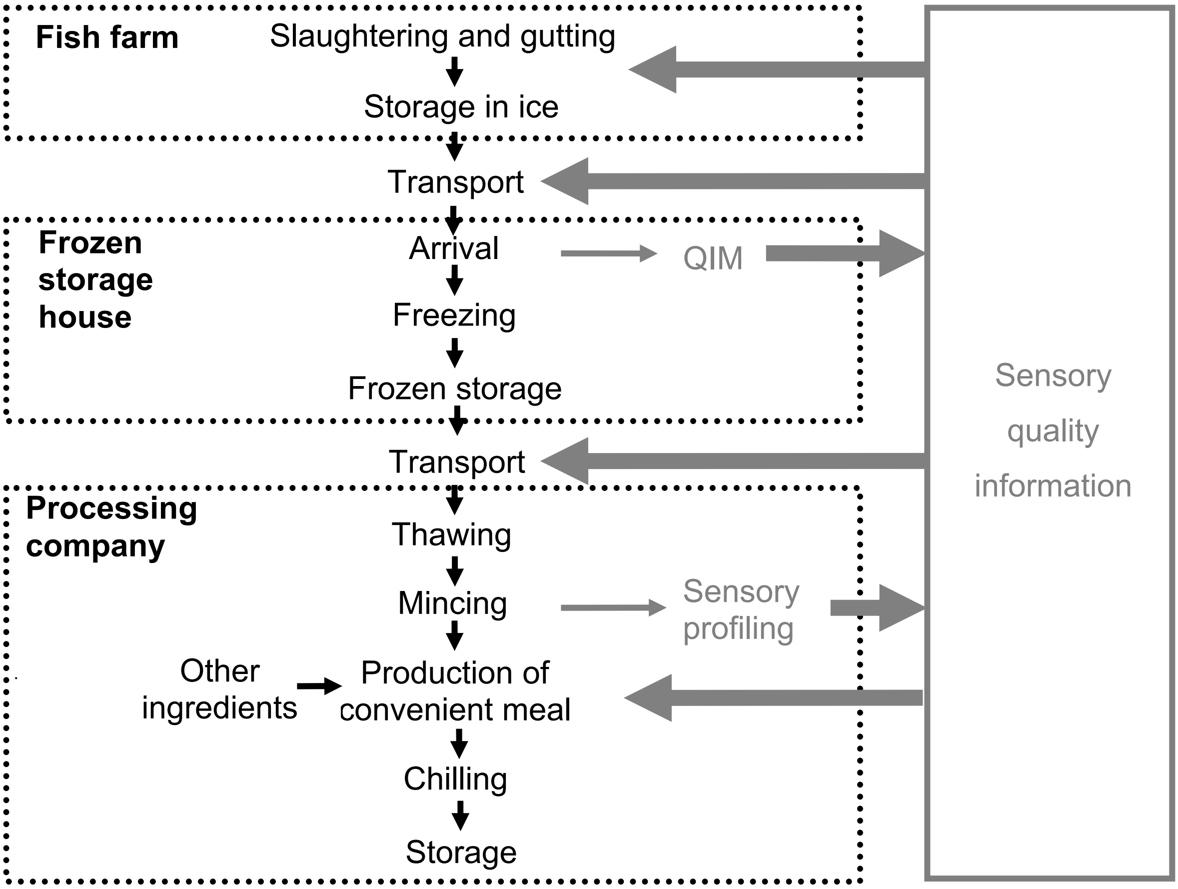

Figure 3.7: Illustration of the simulated seafood production chain in Experiment 4, including the use of the SSQM to communicate sensory quality between different partners in the chain. The experiment only simulates the production chain until the fish is minced, including the sensory profiling. Additionally all relevant sensory measurements are not included in the simulation. Furthermore the whole production chain is not included in the figure or in the experiment since the distribution of the convenience meal to shops and consumer has not been included.

If the findings are put into the perspective of simulating a seafood processing chain, and using the SSQM to communicate sensory quality (Figure 3.7), it can be shown how relating freshness measured with QIM of raw material in the frozen storage house is valuable for predicting sensory quality of the minced product in the processing chain. Therefore the processing company can use the results of the QIM measurements to predict the sensory quality of the minced Rainbow trout. However this demands that QIM results are communicated from the frozen storage house to the processing company. It should however be remembered that the sensory quality in each step of the chain is effected by all the steps which the product has past before the particular step. Therefore other sensory evaluations or other controls, e.g. temperature measurements, than those used in the simulation are relevant to use in real seafood product chains and in SSQM. The results of the QIM evaluations are also relevant for the frozen storage house, the fish farm and for the company performing the transport from the fish farm to the storage house. Similarly, the results from the sensory profiling are relevant for the partners earlier in the chain (see example 1 from Section 3.5.2).

Chapter 4: Conclusion and perspectives

It has been shown that there is a considerable variation in the sensory quality of the salmon products existing on the Danish market. One factor which was found to especially influence the sensory quality was frozen storage time. The experimental work did not give clear results in relation to comparison of the sensory characteristics of the salmon species existing on the market. Additional experiments with samples that have been treated more similarly need to be carried out to obtain knowledge on this subject.

It has been shown that the objective sensory quality of salmon products does have consequences for consumers' preference of products. Salmon products with a low sensory quality, including a discoloured appearance, firm and dry texture, rancid and sour odour plus flavour, had low preference scores. The sensory quality of the samples was affected by the storage method and time. Long frozen-storage time had most influence on the texture of the samples, while storage in ice and MA for a long period had more influence on odour and flavour of the samples. By using clustering analysis it was possible to find clusters of consumers that preferred different storage methods. Additionally small differences in consumers' preferences from the different countries in the experiment were found.

If consumers experience fish products of a low sensory quality, this might reduce their consumption of fish products belonging to the same product category. Furthermore it might also reduce their total consumption of fish, which again can have a negative effect on consumers' health. It is therefore important that the fish available on the market has a high sensory quality. Consequently the seafood industry should generally optimize the sensory quality of its products, and thereby ensure that products with low sensory preference do not reach the final step in the seafood production chain.

The results from the consumer test moreover show that it is possible to analyse consumers' replies to open-ended questions and obtain valuable information about seafood products, since a high agreement between the consumer descriptions and the objective sensory profile performed with the trained sensory panel was obtained. Furthermore additional information about samples was obtained by analysing consumers' descriptions. This information can be used in future experiments. For example consumer comments acquired from consumer tests can be used in relation to defining demands to sensory quality in the seafood production chain.

It has been shown that there can be significant differences in sensory profiles of heat-treated individual Rainbow trout belonging to the same aquaculture production batch and treated in the same way. Additionally, the results show that there can be differences in sensory profiles between groups of trout collected at different times during a production day. Generally the differences in sensory characteristics of individual trout could not be explained by the chemical and physical measurements performed. Additional experiments should be performed to obtain additional information in this area.

The differences in sensory profile of individual fish from a single production batch must be taking under critical consideration when performing scientific studies which include sensory evaluations in the future and also in industrial processing of fish. Generally, both in scientific studies and in industrial processing, the variations will increase the number of samples needed to make sure that valid conclusions are found. In future experiments the number of replicates should therefore be critically considered to ensure that valid conclusions are obtained. Additionally, if possible all assessors in future experiments should, and especially during training, but also in the experiment, get samples from the same fish. If assessors do not get samples from the same fish it cannot be expected that assessors agree in their sensory evaluations. This is a problem in relation to training the assessors, and also in the data analysis of the results. During training it might in some causes be possible to reduce the sample size, and then only train on a subset of the relevant sensory descriptors on each sample. In this way more assessors can get samples from the same fish. However the assessors will need to get more samples.

Communication of demands to sensory quality and results from sensory evaluations in the seafood production chain is essential for optimal use of sensory evaluations in the seafood production chain. Therefore an SSQM which can be used for communicating sensory quality between the partners in seafood production chain is suggested. The SSQM will make it possible to share the understanding of the sensory quality in the chain. Not only results from sensory evaluation and demands to sensory quality can be included in the model, but also other information relevant for sensory quality.

Using the SSQM in the seafood processing chain would increase the general sensory quality of seafood products produced, which again could increase consumer consumption of seafood. Consequently the use of the SSQM would be beneficial for both the seafood processing industry and consumer health. The SSQM and the beneficial effects of using the SSQM should therefore be communicated to the partners in the seafood processing chain. Practical use of the SSQM will demand that systems for the required information flow are developed.

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Paper I

Sensory profiles of the most common salmon products on the Danish market

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SENSORY PROFILES OF THE MOST COMMON SALMON PRODUCTS ON THE DANISH MARKET

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ABSTRACT

The sensory profiles of the most common chilled and frozen salmon products available to consumers on the Danish market were studied. A sensory profiling was made on 12 salmon products varying in salmon species, origin, storage method and time. Samples stored in ice between 7 and 16 days, frozen for 1 month or stored in modified atmosphere for 5 days all had sensory profiles dominated by sea/seaweed odor, juicy and oily texture, fresh fish oil, and sweet and mushroom flavor. Marked differences in the sensory profiles of the frozen samples were found to correlate to differences in storage time. Frozen storage for 6 months resulted in firm texture, discolored appearance and rancid flavor. The samples stored in modified atmosphere for 7 days had a sensory profile with marked rancid and sour odor.

INTRODUCTION

A variety of fish products are available to the consumers on the Danish market. The products are made from various fish species of which salmon is one of the most popular. For salmon, factors such as biological variation, origin, whether or not the fish is farmed or wild, storage time, farming conditions, treatment and storage conditions after catch or slaughtering influence the sensory properties of the products.

Salmonids, especially Atlantic salmon *(Salmo salar)*, on the Danish market are mostly farmed fish. Several studies show how the sensory properties of salmonids are influenced by different farming conditions, e.g., feed composition (Johansson *et al*. 1991; Regost *et al*. 2001). Rasmussen (2001) has published a review on how the quality of salmonids is affected by farming conditions.

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Furthermore, some studies have been carried out in which the sensory qualities of wild and farmed salmonids were compared. Skrede and Storebakken (1986) compared the color of wild and farmed Atlantic salmon (*S. salar*) by using instrumental color analysis and found no significant differences. Sylvia *et al.* (1995) conducted a consumer study on three types of cooked fresh salmon. The three types were farmed Atlantic salmon (*S. salar*) and wild and farmed Chinook salmon (*Oncorhynchus tschawytscha*). The results showed that consumers were able to differentiate between the salmon types based on a variety of descriptors. Farmer *et al.* (2000) studied the sensory characteristics of frozen farmed and wild Atlantic salmon (*S. salar*) and found differences in the texture. The effects of frozen storage time were studied by Waagbø *et al.* (1993), Refsgaard *et al.* (1998), Refsgaard *et al.* (1998) and Farmer *et al.* (2000). Waagbø *et al.* (1993) and Refsgaard *et al.* (1998) both found a significant reduction in the sensory attribute juiciness caused by increased freezing time. The same was found for frozen compared with fresh storage (Waagbø *et al.* 1993).

The sensory and textural changes during ice storage of farmed Atlantic salmon (*S. salar*) were studied by Andersen *et al.* (1995) and Sveinsdottir *et al.* (2002, 2003). Both Sveinsdottir *et al.* (2002) and Andersen *et al.* (1995, 1997) found that hardness measured with an instrumental method decreased during ice storage, and Sveinsdottir *et al.* (2003) found similar results by using quantitative descriptive analysis (QDA).

Salmonid products can also be stored packed in modified atmosphere (MAP). Studies have been conducted on whole Atlantic salmon (*S. salar*) (Sivertsvik *et al.* 1999a,b). In these studies, packaging in modified atmosphere was compared with storage in ice. One of the conclusions was that fish stored in modified atmosphere had an equal or better sensory quality. Randell *et al.* (1999) studied the effect of packaging Atlantic salmon (*S. salar*) filets in different retail packages. The package types included overwrap, vacuum and gas packages. Fletcher *et al.* (2002) studied the spoilage of King salmon (*Oncorhynchus tshawytscha*) fillets that were stored in different atmospheres. Brown *et al.* (1980) studied the effect of modified atmosphere storage compared with storage in normal air of Silver salmon (*Oncorhynchus kisutch*) and found that storage in modified atmosphere compared with air reduced the development of strong aromas.

The studies just described show that there are considerable sensory differences in salmonids and salmonid products. The differences are not only due to wild opposed to farmed fish and various farming conditions, but also due to the storage conditions and storage time. However, the studies used different sensory methods, e.g., a variety of sensory descriptors, which complicates comparing the sensory properties of the different products. It can be difficult to conclude if differences are caused by product types or by different methods.

The purpose of the present study therefore was to get an overview of both sensory properties and differences between the most common salmonid products available on the Danish market. Sensory profiles for the salmonid products were developed. The product samples used in the study varied in storage method, storage time, salmon species, whether the salmon was farmed or wild, and if the salmon was portion-sized before storage.

MATERIALS AND METHODS

Salmon Samples

Twelve different salmon samples were used in the experiment (Table 1). All the samples were obtained from local shops or companies and bought as consumer products. MAP samples were stored at 2C from when they were obtained and until used in the test. Ice-stored samples were stored in ice from when they were obtained and until they were used. The frozen samples were stored at −30C after arriving at the laboratory and until they were thawed. The frozen samples were thawed at 2C for one (FPS and FPL) or two (FW, WE, WIa and WIb) days.

Sensory Evaluation

The panel consisted of 10 assessors, eight female and two male, all experienced in evaluation of fish. The assessors were tested and trained in descriptive sensory analysis according to standards ISO 11035 (1994) and ISO 8586-1 (1993). Before the sensory profiling was carried out, a vocabulary was developed and the assessors were trained in using the vocabulary. This was carried out during four training sessions where the assessors tasted different types of salmon samples that represented the same variation between salmon products as those used in the study. The training sessions were approximately 2 h long. The first training session was qualitative and the aim was to develop a list of descriptors for odor (O), appearance (A), flavor (F) and texture (T). An outline of the descriptors is shown in Table 2. Salmon color was evaluated with a SalmoFan ruler (F. Hoffmann-LaRoche Ltd., Basel, Switzerland) on an interval scale ranging from 20 to 34, where 20 is a lighter salmon color (pink) than 34. The rest of the descriptors were evaluated on an unstructured 15-cm scale anchored 1.5 cm from both ends.

The sensory profiling of samples was performed during four test sessions. In each test session, the assessors evaluated three samples in duplicates. Between six and nine assessors participated in each test session.

TABLE 1.
OVERVIEW OF THE SALMON SAMPLES USED IN THE EXPERIMENT

Sample code	Storage method	Storage time	Species	Origin*	Cuttings for storage, size and packing
MS	MAP 2C	5 days†	*Salmo salar*	Farmed	Pieces of fillets (approximately 125 g)
ML	MAP 2C	7 days†	*Salmo salar*	Farmed	Pieces of fillets (approximately 125 g)
Isa‡	In ice 0C	7 days	*Salmo salar*	Farmed	Gutted but otherwise whole fish (3.5–4.0 kg)
Isb‡	In ice 0C	7 days	*Salmo salar*	Farmed	Gutted but otherwise whole (3.5–4.0 kg)
Isc‡	In ice 0C	7 days	*Salmo salar*	Farmed	Gutted but otherwise whole (3–4.0 kg)
IL‡	In ice 0C	16 days	*Salmo salar*	Farmed	Gutted but otherwise whole (3.5–4.0 kg)
FPS	Frozen	1 month	*Salmo salar*	Farmed	Vacuum-packed pieces of fillets (size 140 g)
FPL	Frozen	6 months	*Salmo salar*	Farmed	Vacuum-packed pieces of fillets (size 140 g)
FW	Frozen	6 months	*Salmo salar*	Farmed	Vacuum-parked gutted but otherwise whole (approximately 3–4 kg)
WE	Frozen	Unknown	*Oncohynchus keta*	Wild	Gutted but otherwise whole fish parked in cardboard box (2.5–3.0 kg)
WIa	Frozen	Unknown	*Oncohynchus kisutch*	Wild	Gutted but otherwise whole fish parked in plastic bags (approximately 3–4 kg)
WIb	Frozen	9 months	*Oncohynchus kisutch*	Wild	Gutted but otherwise whole parked in cardboard box (approximately 3–4 kg)

* All farmed salmon are from Norway and all wild salmon are from the Pacific.
† The age of the fish before it was MAP is unknown.
‡ Sample IL, ISa and ISb are from the same fish farm. Sample IL and ISa are from the same batch. ISc are from another fish farm.
MAP, modified atmosphere package.

Salmon samples were heat-treated in a convection oven at 100C for 15 min before serving. The fish portions were approximately 50 g. Samples were cooked in there own juice without any additives by using the same porcelain trays in which they were later served to the panel. The samples were served in random order with the skin side facing downwards in closed porcelain trays marked with a three-digit code on the lid. The evaluations were performed according to ISO 8589 (1988) in separated booths under normal daylight. The assessors used water and flat bread to clean the mouth between

TABLE 2.
DESCRIPTORS USED FOR SENSORY PROFILING OF SALMON

Descriptor	Description	Scale	
		Minimum (0 cm)	Maximum (15 cm)
Odor			
Sea/seaweed	Fresh seaweed, fresh sea smell	None	Strong
Sourish	Acidic odor, fresh citric acid odor	None	Strong
Sweet	Sweet odor	None	Strong
Rancid	Rancid fish, paint, varnish	None	Strong
Sour	Smell like sour dishcloth/ sour sock	None	Strong
Appearance			
Discolored	Brown or yellow spots, dark areas	None	Strong
Salmon color	Evaluated with a SalmoFan ruler (Roche)*	–	–
Texture			
Juicy	The samples' ability to hold water after 2–3 chews	Dry	Juicy
Firm	Force required to compress the sample between the molars	Soft	Firm
Oily	Amount of fat coating in the mouth	None	Strong
Flavor			
Fresh fish oil	Fresh oil, fresh green hazelnut	None	Strong
Sweet	Sweet, warm milk	None	Strong
Sourish	Acidic, fresh citric acid	None	Strong
Cooked potatoes	Cooked peel potatoes	None	Strong
Mushroom	Mushroom flavor	None	Strong
Rancid	Rancid fish, paint, varnish	None	Strong
Salt	Salt	None	Strong

* Evaluated with a SalmoFan ruler (Roche) on an interval scale ranging from 20 to 34, where 20 is more light salmon color (pink) than 34.

samples. Data were collected using a computer system (FIZZ Network Version 2.0, Biosystems, Couternon, France).

Data Analysis

Salmon color was evaluated by univariate analysis of variance and mean values were calculated for each sample type. The remaining data from the sensory profiling were corrected for level effect by the method of Thybo and Martens (2000). Also, the signal-to-noise ratios (S/N) of the various sensory descriptors and assessors were analyzed by this method. After correcting for level effect, the mean values for each salmon sample on each sensory descriptor were calculated. Principal component analysis (PCA) on mean values was performed to study the differences between salmon samples. The correction for level effect, the signal to noise ratio analysis and PCA were calculated with The Unscrambler 9.1 (CAMO, Trondheim, Norway).

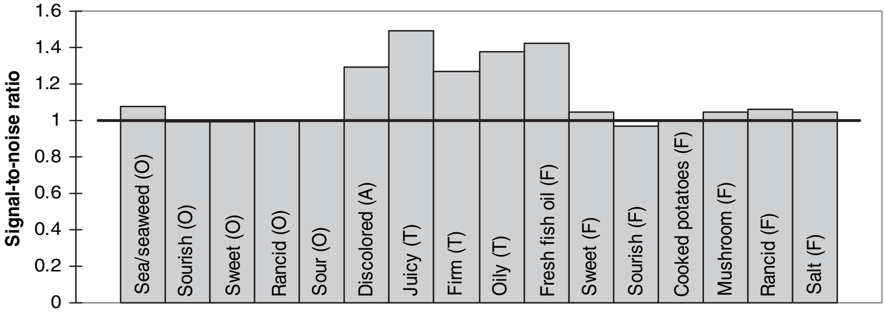

FIG. 1. SIGNAL-TO-NOISE RATIOS FOR ALL THE SENSORY DESCRIPTORS EXCEPT SALMON COLOR
(O) Odor. (A) Appearance. (F) Flavor. (T) Texture. The sensory descriptors are described in Table 2.

RESULTS

S/N of the Sensory Descriptors

Figure 1 shows the S/N for the different sensory descriptors with the exception of salmon color. Descriptors with an S/N lower than one are dominated by noise and their values, therefore, are not reliable. If the S/N for a descriptor is higher than one, the descriptor has discriminating power (Thybo and Martens 2000). In this experiment, the most reliable descriptors (highest S/N) were discolored (A), juicy (T), firm (T), oily (T) and fresh fish oil (F). The descriptors sea/seaweed (O), sweet (F), mushroom (F), rancid (F) and salt (F) were also reliable. The rest of the descriptors all had an S/N close to, but less than one (between 1.00 and 0.97), showing that their values were unreliable.

Differences between Salmon Samples

In Table 3, the mean value for salmon color is shown for each of the 12 samples. Sample WIb (*Oncohynchus kisutch* caught wild and frozen for 9 months) had a significantly darker salmon color than all the other samples.

Figure 2 shows the first two principal components (PC) scores (A) and correlation loadings (B) from a PCA model calculated on the results from the sensory profiling. PC1, which explains 73% of the variation in the data, mainly divide the samples into three groups. One group with a high PC1 score contains all the ice- and MAP-stored samples and FPS (*S. salar* frozen for 1 month) and WE (*Oncohynchus keta*, frozen). The second group, which has a medium low PC1 score, contains FPL and FW (both are *S. salar* frozen for 6 months). The last group has very low PC1 scores and contains WIa and WIb

TABLE 3.
MEAN SALMON COLOR FOR EACH OF THE 12 DIFFERENT SALMON SAMPLES*

Sample	Salmon color	Standard deviation
MS	20.8[b]	1.2
ML	21.8[b]	1.2
ISa	21.8[b]	1.0
ISb	21.8[b]	1.0
ISc	21.3[b]	0.8
IL	21.7[b]	1.0
FPS	21.5[b]	0.8
FPL	21.2[b]	1.5
FW	22.3[b]	0.5
WE	21.8[b]	1.4
WIa	20.6[b]	1.0
WIb	25.7[a]	1.8

* Salmon color was evaluated with a SalmoFan ruler (Roche) on an interval scale ranging from 20 to 34, where 20 is more light salmon color (pink) than 34. Samples with different letters are significantly different ($P < 0.05$). The sample codes are explained in Table 1.

(both frozen samples of *Oncohynchus kisutch*). A high PC1 score is correlated with juicy (T), oily (T), sweet (F), fresh fish oil (F), mushroom (F) and sea/seaweed (O). A low PC1 score is correlated with discolored (A), firm (T) and rancid (F). PC2, which explains 8% of the variation, mainly differentiates sample ML (*S. salar* stored in MAP for 7 days) from the other samples. The main reason is that sample ML has a high intensity of sour (O).

By comparing the information from the S/N plot (Fig. 1) with the correlation loadings, it can be seen that the descriptors with a high S/N all have at least 50% of their variation explained by PC1 and PC2. All these descriptors also have high numerical values of their PC1 correlation loadings. This is not the case for descriptors with a low S/N. Sour (O) is the only descriptor with a low S/N (maximum one) that has more than 50% variation explained by PC1 and PC2. Therefore, PC1, besides explaining more of the information than PC2, also contains more reliable information.

DISCUSSION

The Ice-stored Samples

The four samples stored in ice had very similar sensory profiles. All of the ice-stored samples had a high PC1 score (Fig. 2), and ice storage was correlated

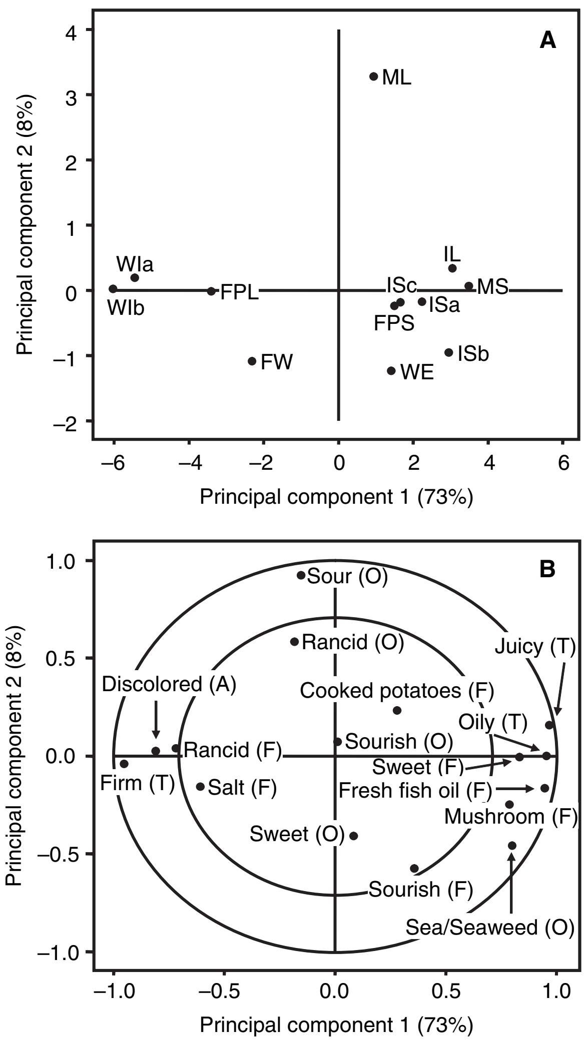

FIG. 2. SCORES (A) AND CORRELATION LOADINGS (B) FROM A PRINCIPAL COMPONENT (PC) ANALYSIS MODEL OF THE SENSORY PROFILES

The sensory descriptor salmon color (A) was not included in the model. PC1 and PC2 explain 73 and 8% of the total sample variance, respectively. The score value labels refer to the samples listed in Table 1.

with the descriptors sea/seaweed (O), juicy (T), oily (T), fresh fish oil (F), sweet (F) and mushroom (F), and negatively correlated with firm (T), rancid (F) and discolored (A). Although the ice storage samples represented different fish farms, different batches and different storage times in ice (7 or 16 days), no clear sensory differences were observed. This is in agreement with Sveinsdottir *et al.* (2002) who found that the most obvious changes in flavor of ice-stored *S. salar* happen after 17–19 days. Sveinsdottir *et al.* (2003) found by using QDA that Atlantic salmon (*S. salar*) apparently becomes less firm and juicy during ice storage. In the present study, a clear effect of storage time on ice was observed for neither juiciness nor firmness.

The Frozen Samples

The sensory profile of samples that had been frozen showed more variation than the iced samples. Part of this variation seems to be related to frozen storage time, and PC1 from Fig. 2 appears to be greatly influenced by frozen storage time. WIb (wild O*ncohynchus kisutch,* frozen for 9 month) was the sample with the longest known storage time and also the sample with the lowest PC1 score, and the sample which differed the most from the ice-stored samples (Fig. 2). A low PC1 score is correlated with firm (T), discolored (A) and rancid (F), and negatively correlated to sea/seaweed (O), juicy (T), oily (T), fresh fish oil (F), sweet (F) and mushroom (F). Sample FW (*S. salar*, frozen whole) and FPL (*S. salar,* frozen as pieces of fillets) both frozen for 6 months, also had low PC1 score values (Fig. 2). Conversely, sample FPS, which had been frozen for only 1 month, had a rather high PC1 score and is, in fact, more similar to the ice-stored samples.

The results show that aside from the texture and flavor of the salmon, an increase in discolored (A) and decrease in sea/seaweed (O) were also observed as a consequence of freezing. Farmer *et al.* (2000) found that moist texture (defined as amount of moisture released on chewing measured with sensory profiling) was significantly reduced and that appearance was affected by freezing of Atlantic salmon (*S. salar*). However, freezing had only little influence on flavor; it was only oily flavor which decreased. Farmer *et al.* (2000) also looked for an effect of freezing time between 2 and 34 weeks and found some on appearance but not on odor, flavor, aftertaste or texture. However, Refsgaard *et al.* (1998) found a significant decrease caused by freezing time on sensory descriptors fish oil taste and juiciness of Atlantic salmon (*S. salar*). These effects were also observed in the present study. Waagbø *et al.* (1993) reported that fresh fillets of Atlantic salmon (*S. salar*) were juicier and less firm than frozen fillets. In addition, they also found changes on the flavor and color with freezing and storage time.

The Samples Stored MAP

The two samples stored in MAP had rather different sensory profiles. Sample MS (*S. salar* MAP and stored for 5 days), WE (wild *Oncohynchus keta*, stored frozen), FPS (*S. salar,* frozen for 1 month) and the samples stored in ice had relatively similar sensory profiles. Sample ML (*S. salar,* MAP packed and stored for 7 days), on the other hand, was rather different from the rest of the samples, although it had only been stored for 2 days more than sample MS. ML was the sample with the highest PC2 score (Fig. 2). A high PC2 score was correlated with rancid (O) and sour (O), and negatively correlated with sourish (F) and sweet (O). As described earlier, PC1 contained more reliable information than PC2. ML also had a lower PC1 value than MS. The reason for this is that ML had a lower intensity of sea/seaweed (O), juiciness (T), oily, (T), fresh fish oil (F) and mushroom (F), and a higher intensity of rancid (F) than MS. The sensory differences between MS and ML were not as big as the sensory differences between some of the frozen samples yet still apparent. The difference between MS and ML may be explained by the difference in storage time, but differences between batches might also be of importance. However, sample Isa, Isb and Isc, which had all been treated the same way but are from different batches, were much more alike than MS and ML. This indicates that the difference between MS and ML was only caused by batch variation.

The Different Salmon Species

The sample set contained a total of three samples of wild fish, all of which had been stored frozen. Two of these samples were of the species *Oncohynchus kisutch* (WIa and WIb) and the last one was of the species *Oncohynchus keta* (WE). The two samples of *Oncohynchus kisutch* (WIa and WIb) had similar sensory properties but were very different from the rest of the samples. Their sensory profile had a high intensity of firm (T), rancid (F) and discolored (A), combined with a low intensity of juicy (T), oily (T), sea/seaweed (O), sweet (F), fresh fish oil (F) and mushroom (F) (Fig. 2). However, there is one clear difference between WIa and WIb. WIb had a darker color than WIa (Table 3). This may be due to differences in catching area, feed and season. The *Oncohynchus keta* (WE) sample was not very different from the ice-stored samples, MS (*S. salar* MAP and stored for 5 days) and FPS (*S. salar* frozen for 1 month as pieces of fillets), whereas it was very different from the two *Oncohynchus kisutch* samples (WIa and WIb). These results indicate that in general the sensory properties of *Oncohynchus keta* and *S. salar* are fairly similar. Furthermore, the results indicate that the sensory properties of *Oncohynchus kisutch* are very different from the sensory properties of *Oncohynchus keta* and *S. salar*.

CONCLUSION

The experiment shows that there is a considerable variation in the sensory profiles of salmonid products available on the Danish market. Some factors affect the sensory characteristics more than others. For example, the storage time of frozen salmon has a considerable influence on the sensory profile of the product, whereas storage times between 7 and 16 days in ice do not substantially influence the sensory profile. The results also show that samples of *S. salar* stored in ice between 7 and 16 days, frozen for 1 month or stored in modified atmosphere for 5 days all have very similar sensory profiles. Both this study and those studies reported in the literature show that not only species, wild or farmed, but also treatment and storage conditions after catch or slaughtering influence the sensory characteristics of the products.

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Paper II

Consumer preference and description of salmon in four Northern Atlantic countries and association with sensory characteristics

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Consumer Preference and Description of Salmon in Four Northern Atlantic Countries and Association with Sensory Characteristics

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The focus in this article is on the relation between consumer preference and objective description of the product profile of salmon. A consumer study of eight salmon products was carried out in Iceland, Denmark, the Netherlands, and Ireland. In addition, objective sensory profiling using a trained sensory panel was performed on the products, which varied according to storage method, storage time, origin, and species. For five out of eight samples, no significant differences in overall liking between the countries were found in the consumer study. However, the consumers gave the samples significantly different descriptions. There was a strong correspondence between the consumer descriptions and the sensory profile.

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KEYWORDS *salmon, preference mapping, consumer preference, open-ended questions, consumer descriptions, descriptive sensory profiling*

INTRODUCTION

Many factors affect consumption of fish; however, one of the most important factors is preference (Bredahl and Grunert, 1997; Brunsø, 2003; Myrland et al., 2000; Olsen, 2003, 2004; Verbeke et al., 2007). An increased understanding of consumer preference of fish and fish products can guide the industry to design products with high consumer preferences, which again can lead to an increased consumption of fish. This would not only be beneficial for the industry but also for the consumer's health (Scientific Advisory Committee on Nutrition, 2004).

The preference of food products depends on the sensory characteristics of the product as perceived by the consumer. This information combined with the consumer's recollection of previous eating experiences, the expectations created for the consumer by the retailer, and the way the fish is presented as a product gives an overall impression of the product (Grunert et al., 1996). Since there is a national variation in traditions, availability of different seafood and frequency of consumption, there is an expected difference in consumer preferences of seafood between different countries. For example, this is seen for smoked salmon (Séménou et al., 2007). The sensory characteristics of fish products vary also from species to species and can be affected by the conditions the fish is living under and handling in the chain from the living fish to consumption (Warm et al., 2000; Rasmussen, 2001; Green-Petersen et al., 2006; Farmer et al., 2000).

Consumer preference depends on the sensory characteristics of the product. Research has shown, however, that it is difficult for consumers to give a precise and well-defined description of the sensory characteristics. On the other hand, an objective and quantitative sensory description can be obtained by using descriptive sensory analysis carried out with a trained sensory panel (Lawless and Heymann, 1998). The objective sensory profile can be related to consumer preference by using preference mapping (Greenhoff and MacFie, 1994; McEwan, 1996). Preference mapping has been used in connection with many different food products; e.g., meat products (Helgesen et al., 1997), coffee (Geel et al., 2005), fruits (Jaeger et al., 2003; Thybo et al., 2003; Jaeger et al., 1998), beer (Guinard et al., 2001), and cheese (Murray and Delahunty, 2000). Preference mapping can not only be used to relate consumer preference to objective sensory profiles but also to quality indictors such as microbiological, physical, or chemical measurements (Greenhoff and MacFie, 1994). Furthermore, it has been shown that preference mapping can be used to relate consumer preference to consumer descriptions of the products (Kleij and Musters, 2003; Faye et al., 2006). In these studies, the consumers' descriptions were obtained by analyzing the consumers' response to open-ended questions. The advantage of using open-ended questions is that it minimizes the risk of affecting the consumers overall liking of the products compared with the use of more specific questions. However, interpretation of open-ended questions might be difficult and pose a risk of misunderstandings. Furthermore, some groups of consumers give more detailed answers than other groups (Lawless and Heymann, 1998).

The authors are aware of only one study of consumer preference for fresh salmon products. Sylvia et al. (1995) studied the acceptability of three types of fresh cooked salmon in Oregon (USA) and found that overall enjoyment of wild Chinook salmon (*Oncorhynchus tschawytscha*) was significantly higher than that of farmed Chinook salmon and farmed Atlantic salmon (*Salmo salar*). Therefore, only limited information is available on consumers' preferences of fresh salmon products and how this preference is affected by different species, origin, and handling. Additionally, there is a lack of information about potential differences between preferences of salmon in different countries. The present article reports the results from a consumer study and a sensory profiling of eight salmon products varying in origin, species, and treatment in the chain from fish harvest until consumption. The consumer study was performed in four different countries.

MATERIALS AND METHODS

Experimental Design

The consumer test was performed in Denmark, Iceland, Ireland, and the Netherlands, simultaneously. The locations for the test were the National Institute of Aquatic Resources (DTU Aqua) in Lyngby (Denmark); Food Research, Innovation and Safety (MATIS) in Reykjavik (Iceland); University College Cork (UCC) in Cork (Ireland); and the Institute for Marine Resources and Ecosystem Studies (IMARES) in IJmuiden (the Netherlands). The salmon products were collected and packed and sent to the other partners by DTU Aqua, where the sensory profiling was also performed. The total experiment was conducted during a period of 2 weeks. In each week, four products were tested in both the consumer test and the sensory profiling. The test weeks had the following time schedule: on Monday, the products were packed and sent by air to the different partners; on Wednesday, the sensory profiling was performed; and on Thursday, the consumer test was performed in all four countries.

Salmon Products

Eight salmon products were used in the consumer and the sensory profile. The salmon products differed with respect to storage method (in ice, frozen, or packed in modified atmosphere), storage time (short or long), origin (wild or farmed), and salmon species (*Salmo salar*, *Oncohynchus keta*, or *Oncohynchus kisutch*). The eight salmon products were chosen in such a way that they represented the most common raw and basic salmon products available to consumers in the test countries. An overview of the products is shown in Table 1. In the sample, codes WE and WI are wild *Oncohynchus keta* and *kisutch*, respectively. F, I, and M are frozen, ice storage, and packed in modified atmosphere, respectively. L and S stands for long and short storage time which is dependent on the storage method (see Table 1). The storage times represent common handling practices for consumer products.

The products were balanced between the 2 weeks. In each week, one frozen sample, one wild frozen sample, one modified atmosphere packed sample, and one sample stored on ice was tested. Additionally, samples were balanced according to storage time. Samples FL, ML, IS, and WI were tested in the first week, while samples FS, MS, IL, and WS were tested in the second week.

TABLE 1 Sample Descriptions: Sample Codes, Storage Method, Storage Time, Species, Origin, and Information on the way Samples were Cut for Storage

Sample code	Storage method	Storage time[1]	Cuttings for storage	Species	Origin[2]
WE	Frozen −20°C	9 months	Gutted but otherwise whole	*Oncohynchus keta*	Wild
WI	Frozen −20°C	8 months	Gutted but otherwise whole	*Oncohynchus kisutch*	Wild
FL	Frozen −20°C	5 months	Pieces of fillets ready for serving	*Salmo salar*	Farmed
FS	Frozen −20°C	1–5 months	Pieces of fillets ready for serving	*Salmo salar*	Farmed
IL	In ice 0°C	15 days	Gutted but otherwise whole[3]	*Salmo salar*	Farmed
IS	In ice 0°C	8 days	Gutted but otherwise whole[3]	*Salmo salar*	Farmed
ML	MA[4] 2°C	7 days on ice +8 days in MAP	Pieces of fillets ready for serving[5]	*Salmo salar*	Farmed
MS	*MA[4] 2°C*	3 days on ice +6 days in MAP	Pieces of fillets ready for serving[5]	*Salmo salar*	Farmed

Description of Sample Codes: WE and WI are Wild *Oncohynchus keta* and *kisutch,* respectively. F, I, and M are frozen, ice storage, and packed in modified atmosphere, respectively. L and S stand for long and short storage time, which is dependent on the storage method.

[1]Storage time before the consumer test.

[2]All farmed salmon are from Norway and all wild salmon are from the Pacific.

[3]Three days before the consumer test the fish were filleted. Fillets were packed in plastic bags which were stored at 0°C.

[4]Packed in modified atmosphere. Gas mixture was 40% CO_2 and 60% N_2.

[5]Before packing in modified atmosphere, the fish were stored gutted but otherwise whole.

Sample MS and ML were stored gutted but otherwise whole in ice before packing in modified atmosphere. However, before packing samples MS and ML in modified atmosphere, they were cut into pieces ready for serving. These pieces were placed in plastic trays, and the trays were packed in a modified atmosphere (40% CO_2 and 60% N_2) by the use of a tabletop vacuum chamber machine (Multivac, Wolfertschwenden, Germany). The gas and fish volume ratio was 2:1. Before freezing, the samples of *Salmo salar* (FS and FL) were cut into pieces ready for serving and vacuum packed. The frozen samples made of *Oncohynchus keta* and *kisutch* (WE and WI) were frozen gutted, but otherwise as whole fish. The fresh ice stored samples (IS and IL) were both stored gutted but otherwise whole, until 3 days before the consumer test when they were filleted. The fillets were packed in plastic bags and placed in polystyrene boxes with ice mats.

The products were sent in polystyrene boxes to the partners for the consumer test. The samples packed in modified atmosphere and fresh samples (MS, ML, IS, and IL) were packed together with ice mats. During air transport, the polystyrene boxes were kept chilled (0–5°C).

After arrival, the frozen samples of *Salmo salar* (FS and FL) were kept in the boxes (at 0–1°C) until 24 hours before the test, and thereafter, placed separately for thawing at 2–4°C. Whole frozen fish (WI and WE) were thawed for 48 hours at 2–4°C before the experiment. Fresh salmon samples (IS and IL) and the products packed in modified atmosphere (MS and ML) were chill stored (0–5°C) from arrival until the consumer test.

All the salmon samples used in both the consumer test and the sensory profiling were served as 40–50 g pieces (approximately $3 \times 7 \times 2$ cm^3 in size) cut from the loin part of the fillet. The serving samples were without skin, and the pin bones were not removed. No additives were added to the samples.

Descriptive Sensory Evaluation

The panel consisted of 11 assessors: six female and five male. All the assessors were tested and trained in descriptive sensory analysis according to ISO standards 11035 (1994) and 8586-1 (1993). All assessors were experienced in objective sensory evaluation of fish and fish products. The sensory descriptors used in the sensory profiling were developed during another experiment (Green-Petersen et al., 2006). An outline of the descriptors is shown in Table 2. The descriptors were evaluated on an unstructured 15-cm scale anchored 1.5 cm from both ends (Lawless and Heymann, 1998). Before the sensory profiling was carried out, the assessors were trained in evaluating the descriptors during three training sessions where the assessors tasted different types of salmon representing the same sample types as the salmon samples in the study. Each training session lasted between 2 and 3 hours.

TABLE 2 Descriptors used for Sensory Profiling of Salmon Performed with the Trained Sensory Panel

Descriptor	Description	Scale Minimum (0 cm)	Scale Maximum (15 cm)
Odor			
Seaweed	Fresh seaweed, fresh sea smell	None	Strong
Sourish	Acidic, fresh citric acid	None	Strong
Sweet	Sweet	None	Strong
Rancid	Rancid fish, paint, varnish	None	Strong
Sour	Sour dishcloth/sour sock	None	Strong
Appearance			
Discolored	Brown or yellow spots, dark areas	None	Strong
Color	Salmon color	Light	Dark
Texture			
Juicy	The ability of the samples to hold water after 2–3 chews	Dry	Juicy
Firm	Force required to compress the sample between the molars	Soft	Firm
Oily	Amount of fat coating in the mouth surfaces	None	Strong
Flavor			
Fresh fish oil	Fresh oil, fresh green hazelnut	None	Strong
Sweet	Sweet, hot milk	None	Strong
Sourish	Acidic, fresh citric acid	None	Strong
Cooked potatoes	Cooked peeled potatoes	None	Strong
Mushroom	Mushroom flavor	None	Strong
Rancid	Rancid fish, paint, varnish	None	Strong
Salt	Salt	None	Strong

In each session, 9 or 10 assessors participated. The samples were evaluated in replicates, and the evaluations were performed according to ISO standard 8589 (1988) in separate booths under normal daylight. The assessors used water and crispbread to clean their palate between samples. Data were collected using a computer system (FIZZ Network Version 2.0, Biosystems, France).

Before serving, salmon samples were heat treated in a convection oven at 100°C for 22 min until a core temperature had reached 70°C. Samples were heat treated in closed porcelain trays also used for serving the samples. The samples were served in random order with the skin side facing downwards, and the porcelain trays were marked with 3-digit codes.

Consumer Test

Approximately 120 consumers were recruited in each country. The requirements for consumers to qualify were that they ate fish at least once a month and that they were at least 18-years-old. For simplification, consumers were qualified on their consumption of any fish, rather than their consumption of salmon alone. In all four countries, salmon is a commonly used fish (Fischer and Larsen, 2002; Honkanen et al., 2005; Sveinsdóttir, 2007); therefore, it can be expected that most fish eaters regularly eat salmon. The consumers were recruited through advertising in newspapers, by means of leaflets, or through e-mail lists of workplaces and universities near the institutes where the tests were conducted. The consumers were informed that they were going to taste salmon products commonly found in supermarkets or stores. After the consumers had participated, they received a gift voucher of €20 to €30 (depending on the country). Only results from consumers who evaluated all eight salmon samples were used in the data analysis.

In each country, four to six sessions were held on each of the two consumer test days. A maximum of 30 consumers participated in each session. The sessions were held between 10 a.m. and 8 p.m. The consumers were placed at numbered tables and sat alone during the test. Samples were served individually. With each sample, the consumers received a questionnaire, which was removed before the next sample was served. The consumers were provided with water. At the beginning of each session, consumers were told how to fill in the questionnaire and instructed to remain silent during the session.

The samples were served to the consumers directly after cooking. Cooking and serving was done according to a randomized serving plan designed for all countries and all sessions.

All samples were prepared and served in aluminium boxes (volume between 140 to 160 mL). The samples were heat treated until their core temperature had reached 70°C. For practical reasons, slightly different cooking methods were used in each country. In Iceland, the samples were cooked at 95–100°C for 7 min in a prewarmed oven (Convotherm Elektrogeräte GmbH, Eglfing, Germany) with air circulation and steam. The samples were not covered. In Denmark, fish samples were cooked covered with aluminium foil for 12 min in a 100°C prewarmed oven (Ratinal, Großküchentechnik GmbH, D-86899, Landsberg a. Lach) with air circulation. In Ireland and the Netherlands, fan ovens were used. The aluminium boxes were placed on trays with a layer of 1–2 cm water (100°C) and placed in a preheated oven (Hotpoint electric single oven with "circulaire" fan cooking, model "Nouvelle 6102," Indesit Co., Peterborough, UK for Ireland; and the Miele H 216 for the Netherlands). The samples were not covered during the heat treatment. The ovens were set at 200°C, but the actual temperature was 100°C due to water evaporation. The samples were cooked for 8 min.

In all four countries, the same questionnaire was used (translated to the local language). The consumers were asked to answer one question about overall liking on a 9-point hedonic scale, ranging from *extreme dislike* (score 1), *neither like nor dislike* (score 5) to *extreme liking* (score 9). On the liking questionnaire, consumers were offered the chance to comment verbally to the following question: “Why did you make this choice?”. When the consumers had tasted all the samples, they answered an additional questionnaire, which included information about fish consumption, behavior, and demographics.

Data Analysis

The results from the sensory profiling were treated by the method described by Thybo and Martens (2000) to correct for level effects (effects caused by level differences between assessors and replicates) and to study the performance of the assessors and the reliability of the sensory descriptors. Because of low signal to noise ratio for two assessors, their evaluations were removed from the data set (for one of the assessors, only data from one of the test days was removed). Afterwards, the data set was corrected for level effects again, and it is this data set that was used in the data analysis.

The results from the consumers’ overall liking were studied using Internal Preference Mapping (Principal Component Analysis [PCA]) and clustering analysis. The clustering analysis was performed on centered liking scores by using K-means clustering. External preference mapping was applied, with the sensory data as the explanatory variables (X-matrix) and the consumer preference scores as the response data (Y-matrix), applying Partial Least Squares Regression (PLSR).

The comments made by the consumers about each product were translated into English. Afterwards, the comments were classified into different groups which were related to the same sensory characteristics. Comments which did not describe anything about the products apart from good or bad, were not used further in the analysis; e.g., “it was a lovely fish” or “this is worse than the last fish.” However, comments such as “good texture” or “very poor taste” were used in the analysis. Other examples of comments were “soft” and “juicy.” Afterwards, duplicate comments for each sample were counted. If a comment was mentioned less than 40 times for all samples it was not used in the further analysis. When a comment is mentioned 40 times and if there is no difference between the samples, the expected frequency (the number of times the comment is mentioned) is five for each sample. For the comments which were mentioned more than 40 times, a chi-square test was performed to seek significant differences between the products. It is recommended (Siegel, 1959) that a chi-square test with as many samples as eight is performed if the expected frequency for all samples but one is at least five. Subsequently, the comments were used in external preference mapping applying PLSR, where the consumers’ descriptions were the X-matrix and consumers’ preference the Y-matrix.

Multivariate analysis was performed using the statistical program Unscrambler ® (Version 8.0, CAMO, Trondheim, Norway). Clustering was performed using XLSTAT (Version 2007.8.01, Addinsoft, NY, USA). Other statistical analysis was performed by using the program Prism (Version 4.2., GraphPad, San Diego, CA, USA).

RESULTS AND DISCUSSION

A total of 381 consumers completed the consumer test. The distribution between countries, gender, age, fish consumption, and average liking for each salmon product is shown in Table 3. There were some differences between the countries. The number of consumers completing the test in Ireland, Iceland,

TABLE 3 Number of Consumers, Distribution of Gender, Age, and Statistics on How Often They Eat Fish as a Main Course and Average Liking Score and Standard Deviation for Each Product and for Each Country and in Total

	Iceland	Denmark	Ireland	The Netherlands	All consumers
Total	121 (32%)	102 (27%)	109 (28%)	49 (13%)	381 (100%)
Gender					
Males	44 (36%)	42 (41%)	39 (36%)	27 (55%)	152 (40%)
Females	77 (64%)	60 (59%)	70 (64%)	22 (45%)	229 (60%)
Age					
18–29	35 (29%)	20 (20%)	58 (53%)	1 (2%)	114 (30%)
30–39	27 (22%)	6 (6%)	19 (18%)	5 (10%)	57 (15%)
40–49	20 (17%)	23 (22%)	10 (9%)	8 (16%)	61 (16%)
50–59	16 (13%)	11 (11%)	9 (8%)	12 (25%)	48 (13%)
60–69	17 (14%)	27 (26%)	8 (7%)	16 (33%)	68 (18%)
70–79	5 (4%)	12 (12%)	4 (4%)	7 (14%)	28 (7%)
80–89	1 (1%)	3 (3%)	1 (1%)	0 (0%)	5 (1%)
Fish for Main Course					
Less than once a month	1 (1%)	1 (1%)	3 (3%)	4 (8%)	9 (2%)
Once a month	7 (6%)	9 (9%)	6 (6%)	5 (10%)	27 (7%)
2–3 times a month	16 (13%)	29 (28%)	23 (21%)	4 (8%)	72 (19%)
Once a week	29 (24%)	35 (34%)	39 (36%)	20 (41%)	123 (33%)
2 times a week	39 (32%)	23 (23%)	30 (27%)	13 (27%)	105 (28%)
3–4 times a week	27 (23%)	3 (3%)	6 (5%)	3 (6%)	39 (10%)
Daily or almost every day	1 (1%)	2 (2%)	2 (2%)	0 (0%)	5 (1%)
Liking Scores					
IL	6.8 ± 1.6^{a}	5.8 ± 2.1^{b}	5.8 ± 2.2^{b}	6.5 ± 2.4^{ab}	6.2 ± 2.1^{a}
IS	6.7 ± 1.7	6.7 ± 1.6	6.6 ± 1.5	6.1 ± 2.3	6.6 ± 1.7^{a}
FL	6.1 ± 2.0	6.5 ± 1.9	6.5 ± 2.0	6.3 ± 2.2	6.4 ± 1.9^{a}
FS	6.5 ± 1.7	6.5 ± 1.6	6.9 ± 1.7	6.2 ± 2.3	6.6 ± 1.8^{a}
WE	4.1 ± 1.6^{b}	5.1 ± 2.0^{a}	4.4 ± 2.0^{ab}	4.7 ± 2.6^{ab}	4.6 ± 2.0^{c}
WI	5.1 ± 1.7^{b}	6.1 ± 1.8^{a}	5.2 ± 2.0^{b}	5.5 ± 2.4^{ab}	5.5 ± 1.9^{b}
ML	6.6 ± 1.7	6.2 ± 2.0	6.2 ± 2.0	6.1 ± 2.5	6.3 ± 2.0^{a}
MS	6.8 ± 1.6	6.4 ± 1.9	6.6 ± 1.7	6.5 ± 2.3	6.6 ± 1.8^{a}

The superscript letters in the column with all consumers indicate significant differences between samples, while the superscript letters in the columns for each country indicate significant differences between the countries for each sample (only the rows with the average liking score and standard deviations).

and Denmark was rather similar, but only about half as many consumers completed the test in the Netherlands. In Iceland, Denmark, and Ireland, more females than males participated. In the Netherlands, the opposite was the case. In Iceland and Ireland, many young people (<40-years-old) participated. In Ireland, the youngest age group (18- to 29-years-old) was particularly well represented with 53%. In the Netherlands, more than 50% of the consumers who participated were older than 59 years, and only 12% were younger than 40-years-old. In total, the age group 18- to 29-years-old was the biggest with 114 consumers, and this age group had a significantly lower consumption of fish than the rest of the age groups in the test. This is in line with studies made by Brunsø (2003), Myrland et al. (2000), Olsen (2003), and Pieniak (2008) showing that older people generally consume more fish than younger people. Pieniak showed that consumers younger than 25 years from Denmark and the Netherlands eat less fish than consumers older than 55 years. In Denmark, there was also lower fish consumption in the age group between 25- and 55-years-old than in the group that was older than 55 years.

In the final questionnaire, a small group of nine consumers had reported that they ate fish less than once a month, which was lower than the criterion set for recruitment. However, these consumers were not removed from the data set during the analysis. In all of the countries, more the 50% of the consumers had fish at least once a week. Fish consumption among the Icelandic participants was generally higher than that of the participants from the other countries, with more than 50% of the Icelandic participants eating fish at least twice a week. This was not surprising since the reported average fish consumption in Iceland is more than twice as much as in the other participating countries (Brunsø, 2003).

The products from *Salmo salar* had the highest average liking score, followed by *Oncohynchus kisutch* (WI) and *Oncohynchus keta* (WE; Table 3). For the products IL, WE, and WI, there was a significant difference between the consumers from the different countries. For the rest of the samples, no significant effect of countries was found. The preference of consumers from the Netherlands was not significantly different from that of any of the other countries. For sample IL, a significantly higher liking score was found in Iceland than in Denmark and Ireland. The Icelandic consumers seemed to agree to a very high extent on liking sample IL, whereas both the consumers from Denmark and Ireland were more diverse in their liking of sample IL. Only 9% of the Icelandic consumers gave sample IL a liking score lower than four, but in Denmark and Ireland this was the case for around 30% of the consumers.

The liking score for sample WI was significantly higher in Denmark than in both Iceland and Ireland. Furthermore, the liking of sample WE was significantly higher in Denmark than in Iceland. For sample WE, the consumers from Denmark seemed to be split into two groups almost identical in size based on the liking score (51% of the Danish consumers gave a liking lower than 5). This was not the case for the consumers from Iceland who were in much more agreement in disliking sample WE (82% of the Icelandic consumers gave a liking score lower than 5).

The slightly different heat treatment methods used in the four countries most likely did not have a substantial effect on the sensory characteristics of the samples since such small differences in liking scores were observed between the countries.

The overall liking scores for the samples made of *Salmo salar* with a long storage time (ML, IL, and FL) were all lower than the overall liking scores for samples with a short storage time with the same treatment (MS, IS, and FS), and there was a significant effect of short and long storage time for the *Salmo salar* samples. The average liking score and standard deviation for all samples of *Salmo salar* with a long and short storage time were 6.3 ± 2.0 and 6.6 ± 1.8, respectively.

No significant connection was found between consumers' liking scores and self-reported consumption of fish, in general, and different types of salmon products.

Figure 1 shows the second and third principal component (PC2 and PC3) from an internal preference mapping (PCA model) of the eight products. PC1 explained 30% of the variation due to the variation in consumer preference, but it is not shown because it did not separate the product (it only showed whether the consumers gave high or low preference scores). PC2 and PC3, which explain 16% and 12% of the variation, respectively, on the other hand, separate the products. PC2 separates products WE and WI from the other products, while PC3 mostly separates sample IL from the other samples. Three clusters were identified based on the liking scores (Table 4 and Figure 1). Cluster 1 gave low liking scores to sample FL, WE, and WI. None of the other clusters gave low liking scores to sample FL. Cluster 1 also gave relatively low liking scores to the samples which had been stored in modified atmosphere, but high liking scores to sample IL.

Cluster 2 was the cluster with the highest amount of consumers, and it had many similarities with the overall results: they gave sample FS a remarkably low liking score (the liking score for sample FS in Cluster 2 is significantly different from the liking scores of all the other samples).

Cluster 3 gave high liking scores to sample WI; in fact, the liking score of sample WI was not significantly different from sample FL, MS, FS, and IS (in Cluster 3). Furthermore, the consumers in Cluster 3 disliked sample IL, as they gave a significantly lower liking score to IL than to all the other samples.

No significant differences were found between the three clusters based on gender and the amount of consumption of fish as main course. However, a significant effect was found with country and age (Table 4). The effect of country and age was mainly based on the difference

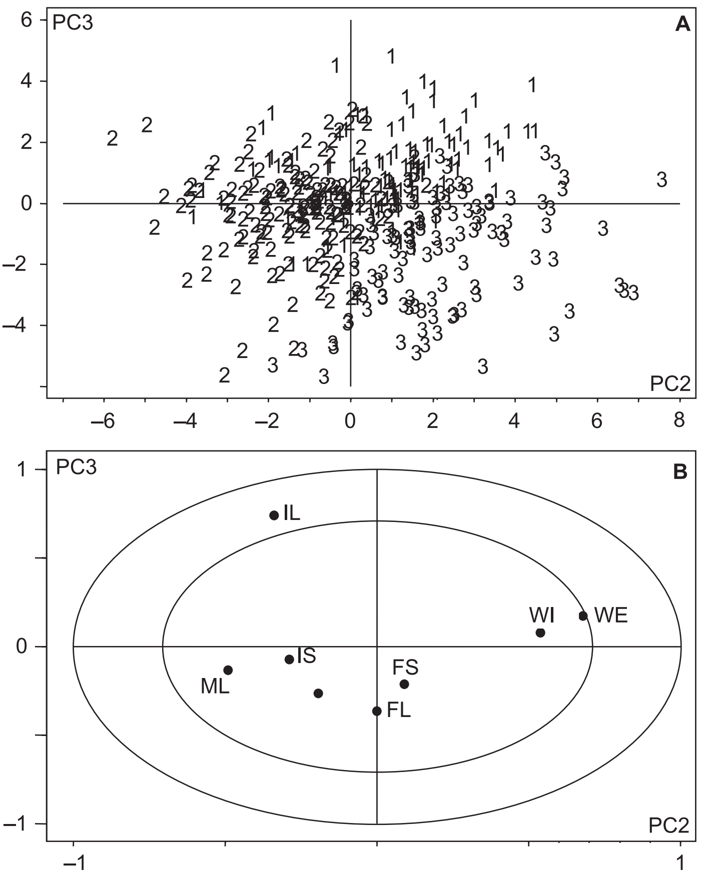

FIGURE 1 Internal preference map. PCA model of the consumer liking scores: (A) the numbers show the three clusters and (B) correlation loadings from PC2 and PC3 which explains 16% and 12% of the variation. The sample codes are explained in Table 1.

between consumers from Iceland and Denmark. Most consumers from Iceland were in Clusters 1 and 2 while more than half of the consumers from Denmark were in Cluster 3. Cluster 3 gave low liking scores to sample IL and high liking scores to sample WI, as the Danish consumers generally did also. Furthermore, Cluster 3 had many consumers in the age group between 60- to 69-years-old (27%); likewise, many of the Danish consumers were in this age group (26%). Cluster 3 also had few consumers in the age between 40- to 49-years-old (13%); while Cluster 2 had many consumers between 40- to 49-years-old (21%), but few consumers between 60- to 69-years-old (13%). There are many consumers from Iceland that belong to the age group 40- to 49-years-old in Cluster 2. Ninety percent of the consumers from Iceland in this age group were in Cluster 2.

TABLE 4 Number of Consumers and Average Liking Score and Standard Deviation for Each Product in Each of the Three Clusters

Sample	Cluster 1	Cluster 2	Cluster 3
Number of Consumers	116 (31%)	153 (40%)	112 (29%)
Country			
Iceland	42 (36%)	66 (43%)	13 (12%)
Denmark	23 (20%)	27 (18%)	52 (46%)
Ireland	31 (27%)	46 (30%)	32 (29%)
The Netherlands	20 (17%)	14 (9%)	15 (13%)
Age			
18–29	33 (28%)	47 (31%)	34 (30%)
30–39	18 (16%)	24 (16%)	15 (13%)
40–49	14 (12%)	33 (21%)	14 (13%)
50–59	19 (16%)	21 (14%)	8 (7%)
60–69	18 (16%)	20 (13%)	30 (27%)
70–79	12 (10%)	8 (5%)	8 (7%)
80–89	2 (2%)	0 (0%)	3 (3%)
Liking Scores			
IL	6.8 ± 1.7^{a}	7.0 ± 1.5^{a}	4.6 ± 2.1^{a}
IS	6.4 ± 1.9	6.8 ± 1.6	6.5 ± 1.7
FL	5.1 ± 2.1^{b}	6.8 ± 1.7^{a}	7.0 ± 1.7^{a}
FS	6.9 ± 1.8^{a}	6.2 ± 1.8^{b}	6.8 ± 1.7^{a}
WE	5.4 ± 1.7^{a}	3.1 ± 1.3^{b}	5.6 ± 2.1^{a}
WI	5.3 ± 1.9^{b}	4.9 ± 1.9^{b}	6.5 ± 1.6^{a}
ML	6.2 ± 1.9	6.7 ± 1.9	5.9 ± 2.1
MS	6.0 ± 2.0^{b}	7.0 ± 1.5^{a}	6.8 ± 1.7^{a}

The superscript letters indicate significant differences between the clusters for each sample (only the rows with the average liking score and standard deviations).

Consumer Liking and Objective Sensory Profiles

The signal to noise analysis performed on the results from the objective sensory profiling showed that all the sensory descriptors had a signal to noise ratio higher than one. Therefore, all descriptors were classified as reliable (Thybo and Martens, 2000) and used in the further analysis.

The relation between consumer liking and the objective sensory description was studied using external preference mapping (Figure 2). In both the sensory profiling and the consumer test sample, WE was the most different from the rest of the samples. The first PLS factor explains the difference between sample WE and the rest of the samples. The consumers gave low liking scores to sample WE, and the reason for this is explained by the sensory profile. The sensory profile of sample WE had a high intensity of sour and rancid odor, salt and rancid flavor, discolored appearance and firm texture, combined with a low intensity of sweet and sourish odor, sea/seaweed, fresh fish oil, cooked potatoes, mushroom, sweet and sourish flavor, oily and juicy texture, and color appearance.

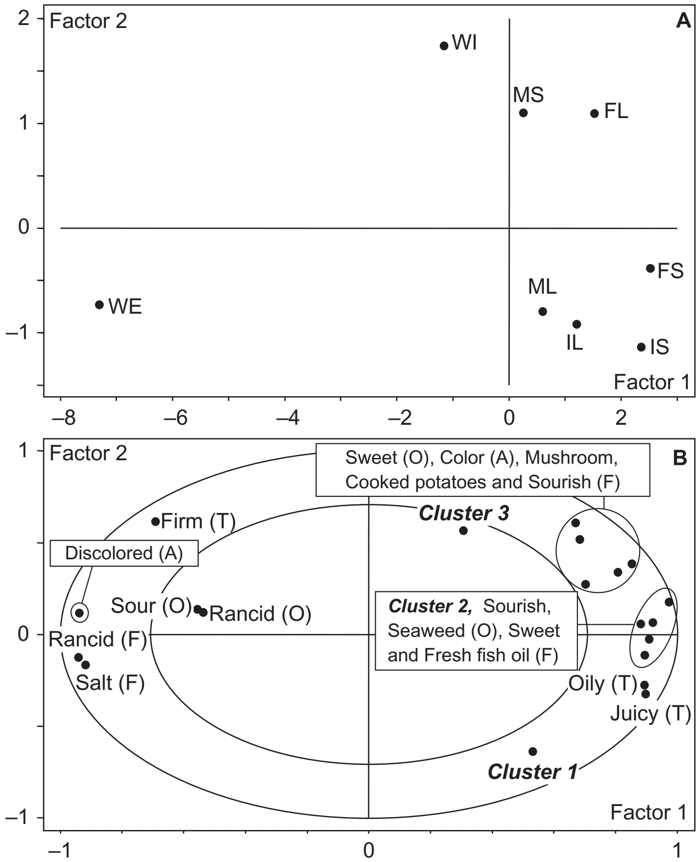

FIGURE 2 External preference map with sensory profiles. PLS model with the sensory profile as X and the average liking scores for each cluster as Y: (A) scores and (B) X and Y correlation loadings from the first and second PLS factor, which explains 70% and 11% of the variation in X plus 58% and 13% of the variation in Y. A, O, F and T are appearance, odor, flavor, and texture, respectively. The sample codes are explained in Table 1 and sensory descriptors are defined in Table 2.

Sample WI had the second lowest score in the first PLS factor and the highest score in the second PLS factor. The sensory profile of WI had a high intensity of sour and rancid odor, discolored appearance and firm texture. Together with a low intensity of sea/seaweed odor, fresh fish oil flavor, oily and juicy texture, the intensity was not as low as for sample WE. WI was most like WE in the sensory profiling.

Most of the consumers (Cluster 1 and 2) gave sample WI low liking scores. However, this was not the case for the consumers in Cluster 3. Cluster 3 also liked sample MS with a high intensity of firm combined with a low intensity of juicy in the sensory profiling compared to the other samples of S*almo salar*. In addition, the consumers in Cluster 3 liked sample FL, but disliked sample IL in contrast to Cluster 1. The main sensory difference between sample FL and IL is that sample FL has a high intensity of salmon color, cooked potatoes, sourish and mushroom flavor.

The second PLS factor in the external preference map (Figure 2) shows the differences between the samples made of *Salmo salar*. The samples made of *Salmo salar* with a long storage period (FL, IL, and ML) compared to samples with a short period (FS, IS, and MS) had a higher intensity of the sensory descriptors of sour odor, rancid odor and flavor combined with a low intensity for fresh fish oil flavor and oily texture. This probably explains the lower liking scores for the samples with long storage time compared to those with a short storage time. The sensory characteristics of ice stored salmon (*Salmo salar*) do not change much during the first 2 weeks of storage (Sveinsdóttir et al., 2002, 2003; Green-Petersen et al., 2006). However, at the end of shelf life sour, rancid, amine, and musty odor; sour, amine, and rancid flavor; and discoloration is evident (Sveinsdóttir et al., 2002, 2003).

The samples WE and WI were different from the rest of the samples. The reason might be the differences between the species and also the prolonged frozen storage (Table 1). In an earlier experiment, sensory characteristics of *Salmo salar*, *Oncohynchus keta*, and *Oncohynchus kisutch* were compared (Green-Petersen et al., 2006) by using a trained sensory panel. Here it was found that the samples of *Oncohynchus keta* were not particularly different from the samples of *Salmo salar*, while the sample of *Oncohynchus kisutch* showed a greater difference to the *Salmo salar*. Both sample WI and WE have been frozen for a longer period than any of the other samples. That freezing can be of importance is confirmed by Farmer et al. (2000) and Waagbø et al. (1993). Both reported a reduction in juiciness caused by freezing of salmon. Moreover, Waagbø et. al. and Refsgaard et al. (1998) found a significant reduction in juiciness during frozen storage.

Consumers' Descriptive Comments on the Samples

Twenty-seven comments were mentioned at least 40 times. For 18 out of the 27 comments, a significant difference was found between the samples (Table 5). Nine out of the 18 comments which were significantly different were related to the texture of the samples, while only one was related to the odor. This suggests that the texture of salmon either was a very important factor for the liking of the product or that the texture was easier to describe.

Figure 3 shows scores and correlation loadings from an external preference map calculated with the significant comments and average liking scores of the clusters. The comments which seemed to be contradictory to each other (firm/soft, juicy/dry, good texture/bad texture, and good flavor/bad flavor) are generally also placed opposite of each other in the loading plot. However, the comments "pink color" and "light color," which can also be understood as opposite terms, were not placed in opposed directions.

TABLE 5 Comments Which are Mentioned at Least 40 Times in Total for all Eight Samples. The Numbers Show How Many Times Each Comment was Mentioned for Each Sample. The Table also Shows the Significant Level (*p* Values) for Each Comment. Samples with a *p* Value Higher than .05 were not Significant (NS)

Comments	WE	WI	FL	FS	IL	IS	ML	MS	*p* Value
Appearance									
Light color	31	2	11	10	7	6	11	9	<.0001
Pink	14	25	7	2	3	2	3	5	<.0001
Proteins[1]	4	8	6	5	7	9	8	9	NS
Flaky	4	9	7	3	2	2	8	5	NS
Good	13	28	31	46	36	28	24	32	.0017
Bad	71	34	17	4	12	8	17	13	<.0001
Odor									
Neutral	7	9	7	13	13	8	7	4	NS
Good	16	12	20	18	13	10	18	18	NS
Bad	7	7	4	2	13	5	7	2	.032
Flavor/Taste									
Strong	10	11	17	10	8	11	11	14	NS
Neutral	73	73	31	44	63	64	45	40	<.0001
Off flavor	7	6	4	6	3	4	6	6	NS
Aftertaste	21	16	23	12	15	14	20	22	NS
Fish	6	10	8	5	3	4	3	5	NS
Good	41	60	99	98	92	98	84	95	<.0001
Bad	59	43	34	30	30	16	31	21	<.0001
Texture									
Firm	47	63	41	36	15	19	18	21	<.0001
Soft	0	1	6	11	28	23	30	28	<.0001
Juicy	2	4	12	12	13	18	16	20	.0012
Dry	86	81	28	35	8	9	12	14	<.0001
Tender	2	1	9	14	31	19	22	18	<.0001
Tough	88	61	22	12	8	8	8	10	<.0001
Rubber	9	10	8	3	4	4	0	3	.019
Good	13	23	41	53	49	47	46	26	<.0001
Bad	15	22	7	8	12	4	10	6	.0016
General									
Watery	8	3	3	8	6	1	7	6	NS
Fatty	7	7	31	25	42	43	45	42	<.0001

[1]This refers to white stuff, egg white.

This was because of the comments on sample WE (sample WE had many comments on both pink and light color). Since fish is a biological material it is possible that there were large variations in the color of the individual fish in sample WE.

The first PLS factor (Figure 3), clearly separates samples WI and WE from the other samples. The consumers characterized samples WI and WE by using comments such as "bad appearance, neutral and bad flavor/taste, bad, tough, dry, rubber, and firm texture." There were some differences between the comments on WE and WI. Sample WE received more comments with respect to tough, light color, bad appearance, and flavor; while WI had

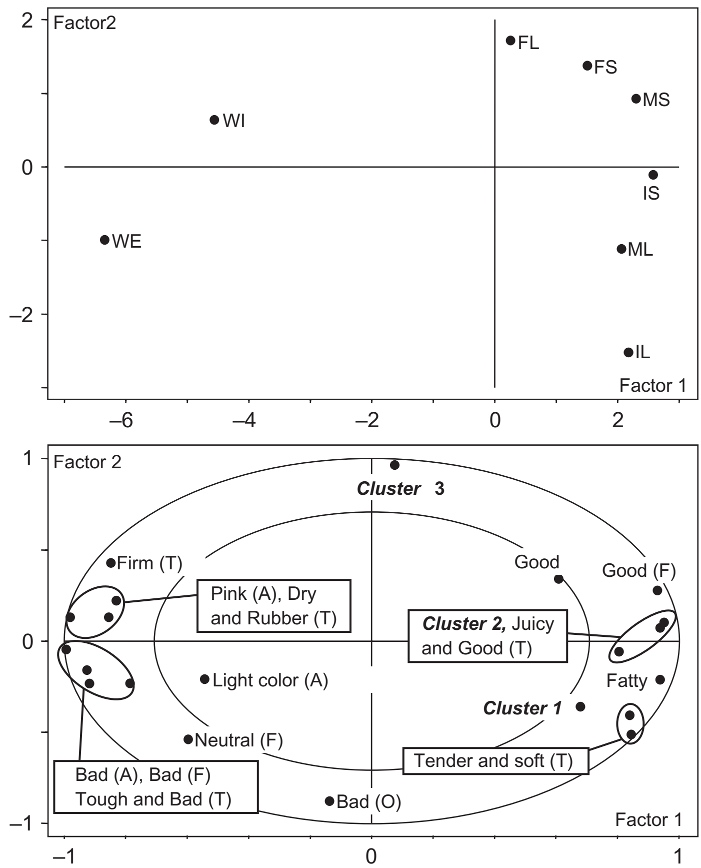

FIGURE 3 External preference map with consumer descriptions. PLS model with the consumer descriptions (Table 5) as X and average liking scores for each cluster as Y: (A) scores and (B) X and Y correlation loadings from the first and second PLS factor, which explains 67% and 12% of the variation in X, plus 64% and 22% of the variation in Y. A, O, F, and T are appearance, odor, flavor, and texture, respectively. The sample codes are explained in Table 1.

more comments on firm, pink, and good flavor. In total, sample WI was more positively described than sample WE, which was consistent with the significantly lower liking score for WE than that for sample WI and the results from the sensory profiling.

The consumers had, on the other hand, described samples FL, FS, ML, MS, IL, and IS with comments such as fatty and good flavor, soft, juicy, tender, and good texture and gave these samples high liking scores. Therefore, it was reasonable to conclude that the comments do reflect consumers' overall liking.

The second PLS factor mainly describes the difference between samples FL, FS, and MS compared to samples ML and IL, which also is related to differences between Clusters 3 and 1. Samples FL and FS had both been frozen, and they had the highest score in the second PLS component. ML and IL had also been stored in modified atmosphere and in ice, respectively, but for a longer time, and these samples both had low scores in the second PLS factor. Samples ML and IL were correlated with the comment "bad odor." This suggests that the quality of these two samples had been decreasing due to storage time and furthermore that the consumers recognized this quality change. Together with samples IS and MS, they were also described as being fatty, soft, and tender. Samples FL and FS, on the other hand, were more frequently described as having a firm and dry texture, but not as frequently as samples WE and WI. The consumers in Cluster 3 did not like the samples which had a bad odor. They appeared to like the samples which were firm and dry; however, not as dry and firm as sample WE, while the opposite was true for the consumers in Cluster 1.

Comparison of Consumer Description and Sensory Profile

There were many similarities between the sensory profile and the comments made by the consumers. This is in agreement with the results found by Kleij and Musters (2003) and Faye et al. (2006). For instance, salmon color from the sensory profile is correlated with the consumer comment "pink." The comment "fatty" was correlated with oily texture from the sensory profile. There is also a clearer agreement between the consumers' use of the comment "firm/soft" and "firm" from the sensory profiling. That is also the case for "dry/juicy." Exceptions to these similarities are "firm/soft" and "dry/juicy." In the sensory profile sample, MS was found to be firm and dry but this was not reflected in the consumers' comments. Additionally, sample FS and FL had many comments indicating that the samples were more firm/less soft than the rest of the samples which were made of *Salmo salar*, and this was not found in the sensory profiling. The reason for the differences in sensory profiling and the comments of "dry/juicy" and "firm/soft" might be due to the differences between the individual fish used to prepare the samples. Since only a small number of fish were tested in the sensory profiling, this biological variation could have more influence on the results from the sensory profiling.

The consumers' descriptions and the results from the objective sensory profiling together provide valuable information. This can be used to give a better understanding of how the consumers perceive the sensory characteristics of the samples. The samples which are found to be discolored in the sensory profile are described by the consumers as having a bad appearance. The consumer comments "neutral" and "bad flavor" were mostly used on samples which in the sensory profile were found to have a rather high intensity of rancid flavor combined with a low intensity of fresh fish, oily, sourish, mushroom, and cooked potatoes flavor. Similarly, the consumer comment "bad odor" is correlated with "rancid" and "sour odor" from the sensory profile. Furthermore, not all the sensory attributes mentioned in the consumers' comments ("tender, tough, and rubber") were covered by the descriptors used in the sensory profiling.

CONCLUSIONS

The various salmon samples had different sensory profiles, and this difference obviously influenced consumer preference. All the samples used in the study represented products available to the consumers on the market, and therefore the variation found in the sensory profile and consumer liking shows that there is a considerable variation in the sensory quality of salmon products that are available to the consumers. If consumers have experience with fish products of a low sensory quality, it might reduce their consumption of fish products belonging to the same product category. Furthermore, it might also reduce their total consumption of fish, which again can have a negative effect on their health. It is, therefore, important that the fish available on the market have a high sensory quality.

For most of the salmon samples, no significant differences in liking were found between the consumers from Iceland, Denmark, Ireland, and the Netherlands. However, for three of the samples, significant differences were found. The biggest difference was found between the consumers from Iceland and Denmark. This indicates that a fish product popular in one country is not necessarily popular in another country. The result also shows that there were variations in preference between the consumers from the same country.

The sensory quality of the samples was, as expected, affected by the storage method and time. Long frozen-storage time affected the texture of the samples, while storage in ice and modified atmosphere for a longer period had more effect on the odor of the samples. By using clustering analysis, it was possible to find clusters of consumers who preferred either frozen storage or storage in ice or modified atmosphere.

The consumer descriptive comments showed that the consumers' differentiation between the products was significant, and there was a high agreement between the consumer descriptions and the sensory profile obtained with the trained sensory panel. Furthermore, the results suggest that the comments from the consumers can be used to obtain additional information on sensory characteristics and on the way the consumers perceive the sensory characteristics of the samples.

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Paper III

Variation in sensory profile between individual Rainbow trout *(Oncorhynchus mykiss)* from the same production batch

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Variation in Sensory Profile of Individual Rainbow Trout *(Oncorhynchus mykiss)* from the Same Production Batch

Ditte Marie Benedikte Green-Petersen and Grethe Hyldig

Abstract: The variation in sensory profile of rainbow trout (*Oncorhynchus mykiss*), belonging to the same aquaculture production batch and handled the same way, was explored by using objective sensory profiling on heat-treated minced fillets. In addition, quality index, mechanical texture, pH, fat, and water content were measured. Different groups of fish were sampled 3 different times during a production day. The results showed significant differences in the sensory profiles of individual fish within all 3 groups as well as significant differences between the groups. Differences in mechanical texture were found between individuals in 2 of the 3 groups and between the groups. No differences were found in quality index neither between individuals nor groups. A significant negative correlation between lipid content and firm texture was observed, but in general, the chemical and physical measurements could not explain the differences in the sensory profiling or in the mechanical texture measurements. The results showed that significant differences in the sensory profiles of individual fish from the same aquaculture production batch may occur. Furthermore, the results also showed sensory differences between groups of samples taken at different times during a production day.

Keywords: descriptive analysis, fish, individual differences, rainbow trout, sensory

Practical Application: Based on the conclusion from this study, it is generally recommended to perform objective sensory measurements on aquaculture fish either by giving all sensory assessors samples from the same fish or by using an appropriate number of replicates to assure that a sufficient number is used to obtain a valid conclusion.

Introduction

Variation in chemical composition of individual fish of the same species from the same batch have been reported, especially with regard to the lipid content (Refsgaard and others 1998; Katikou and others 2001; Nielsen and others 2005a; Løje 2007; Schlechtriem and others 2007). Katikou and others (2001) found that lipid content in Atlantic salmon (*Salmo salar*) from the same production batch differed from 7% to 24% and Løje (2007) found variation between 4% and 11% in lipid content in fillets from Rainbow trout (*Oncorhynchus mykiss*). The chemical composition of fish can influence the sensory characteristics of the fish. Robb and others (2002) found that lipid content of smoked and cooked Atlantic salmon (*S. salar*) has a significant effect on both texture and flavor. In addition Einen and others (1999) have found that variation in lipid content, obtained by using different feed rations, influence sensory-measured texture, and the appearance of smoked Atlantic salmon (*S. salar*). It has also been reported that lipid content of rainbow trout (*O. mykiss*) effects the texture (Fauconneau and others 1993; Andersen and others 1997; Johansson and others 2000). Similarly, it is known that there are differences in the texture between different parts of the fillets exist for Rainbow trout (*O. mykiss*) (Hansen and others 2000; Mørkøre and others 2002) and Atlantic salmon (*S. salar*) (Sigurgisladottir and others 1999; Jonsson and others 2001; Casas and others 2006). Comparable findings can occur in the farming of other animal types, for example, instance cattle (Chamul 2007).

Variations in sensory characteristics of individual fish from the same aquaculture batch can therefore be expected. However, the literature on sensory variation of fish or other animals reared and handled the same way is to the knowledge of the author limited. This is striking since the sensory characteristics of fish products as well as other food products clearly have a significant influence on consumers' liking. Furthermore, several research projects (for example, Regost and others 2001) are studying the effects of factors, such as the influence of feed types used in aquaculture, on the sensory properties.

Variation in sensory characteristics of fish from the same production batch can have a significant influence in the industrial production of fish and fish products as well as for the results of scientific studies. In scientific work with aquaculture fish, the purpose is often to study the effect of different treatments. If there is considerable variation between the individual fish, it will increase the needed number of samples needed to give a valid conclusion. This is especially the case for fish species with a limited size because each assessor will taste samples from different fish, resulting in a nonconclusive evaluation. This will be a problem in relation to training of sensory assessors, but also in sampling and during data analysis.

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Knowledge about significant difference in sensory properties of aquaculture fish is also an advantage in relation to the industrial production of fish and fish products. In the industrial production, some fish might be more suited for one product than another product depending on the sensory properties of the fish, and it might be an advantage to screen the fish in order to support the decision. If no relevant variation is shown in the sensory properties of the fish from the same batch, then the whole batch can be used for the same production. If relevant variation in sensory properties is noticed, the fish can be graded according to the properties. This requires a nondestructive measurement on the individual fish and that the results can be related to the relevant variation in the sensory characteristics of the fish. The measurements can be sensory evaluations but also chemical or physical measurements.

In this study, the variation in objective sensory properties between individual Rainbow trout (*O. mykiss*) belonging to the same production batch treated in exactly the same way is studied. In order to answer the following question: What is the variation in the sensory quality of fish from the same aquaculture product batch and how big is it? The sensory methods used were supported by mechanical texture and pH measurements, data about weight and length, and measurements of lipid and water content.

Material and Methods

Experimental design and material

Rainbow trout (*O. mykiss*) from the same fish farm (Musholm Lax, Gørlev, Denmark) and the same production batch were used. The fish were randomly picked out from the production line, just after they were gutted and graded according to the weight. All the fish belonged to the same weight class (weight between 3 and 4 kg).

To have a sampling over time, groups of fish were taken out of one industrial production line 3 times during a production day. There was 1 h between the 3 groups (X, Y, and Z) and each group consisted of 10 fish. All fish and groups of fish were treated the same way during farming, slaughtering, and handling. The 30 fish were identified with a number and a letter (0X to 9X, 0Y to 9Y, and 0Z to 9Z). The fish were packed in ice, transported to the laboratory, and stored in ice (0 °C) for 3 d. Then, all fish were weighed, the length was measured and the fish were evaluated using the Quality Index Method (QIM) (Bremner 1985; Hyldig and Green-Petersen 2004).

After the QIM evaluation, the fish were for practical reasons frozen at −30 °C for 2 to 3 mo until the last part of the experiment was performed. This part of the experiment was performed during a period of 5 wk. In each of these weeks, measurements were performed during 3 d. On each experimental day, 3 or 4 fish were evaluated.

The fish were thawed by storing the fish at 2 °C for 3 d before the experimental day. Afterwards, the fish were filleted and trimmed. A sample (5-cm wide) under the dorsal fin was cut out of each fillet. These 2 pieces were then divided in 2 (making 4 pieces from each fish) and used for measuring mechanical texture. The rest of the fillets were cut in strips (approximately 3-cm wide) and the strips from each fish were mixed manually before they were minced on a mincing machine (5 mm). The mince was again mixed manually. Samples of the minced fish were frozen at –80 °C and used for determining pH, lipid and water content. The rest of the minced fish was used in the sensory profiling that was performed the same day the fish was minced (the experimental day). Sensory profiling was performed on minced samples to ensure that all samples were as similar as possible.

A reference sample was used to calibrate the panel (Nielsen and others 2005b). The reference samples were made of Rainbow trout (*O. mykiss*) from the same farm as the fish in the study, but from another production batch and production day. This reference was chosen to insure that the reference was comparable but not identical to the fish in the experiment. In total, 21 fish were used to produce the reference sample. All these fish were stored 3 d on ice before they were filleted and cut in strips (approximately 3-cm wide). The strips from all 21 fish were mixed together. Then the strips were minced and afterwards mixed in the same way as the fish used in the study. The minced fish meat was vacuum packed in plastic bags (1 for each day of sensory measurement) and stored at –80 °C until the experimental day.

QIM evaluations

The QIM panel consisted of 4 assessors all tested in performing sensory analysis according to international standards (ISO 11035) and trained in the QIM evaluations (Martinsdóttir and others 2001). In addition, they were specially trained in QIM evaluations of Rainbow trout (*O. mykiss*) during 2 training sessions.

The QIM scheme for Rainbow trout (*O. mykiss*) (Green-Petersen and others 2010) was used in the evaluations and is shown in Table 1. The QIM evaluations were performed under standardized conditions at room temperature using artificial daylight and with no disturbances. Each Rainbow trout was marked with a randomly selected 3-digit code and placed randomly on cooler bricks (2 °C, 80 × 60 × 2 cm) 20 min before the evaluation. All 4 assessors evaluated all fish. From the results, the quality index (QI) was calculated and used in the further analysis.

Sensory profiling

The panel consisted of 11 assessors. Between 7 and 11 assessors participated on each test day. All assessors were selected, tested, and trained in descriptive analysis of Rainbow trout according to standards (ISO 11035; ISO 8586-1; NMKL 21 2008). The sensory descriptors are shown in Table 2. Each descriptor was evaluated on an unstructured 15-cm scale anchored 1.5 cm from both ends. The assessors were trained in using the descriptors during 3 training sessions before the sensory study was performed. In the training sessions, the assessors tasted samples similar to those used in the study. Each training session lasted 2 to 3 h. During the training, the assessors together with the panel leader evaluated the reference sample and determined the intensity for each descriptor.

The mince was shaped as a hemisphere with a portion deviser (Stöckel portionierer CR, Size 12, Stöckel Söhne GmbH,

Table 1–The QIM scheme (Green-Petersen and others 2010) used in the evaluation of the Rainbow trout.

	Quality parameters	Points
Skin	Color/appearance	0 to 2
	Mucus	0 to 1
	Odor	0 to 2
	Texture	0 to 2
Eyes	Pupils	0 to 2
	Form	0 to 2
Gills	Color/appearance	0 to 2
	Mucus	0 to 2
	Odor	0 to 3
Abdomen	Blood in abdomen	0 to 1
	Odor	0 to 2
Quality Index total		0 to 21

S: Sensory & Food Quality

Germany) and placed in porcelain trays with lids marked with a randomized 3-digit code. Samples were heat treated in a convection oven at 100 °C for 22 min to a core temperature of 70 °C. Before all sessions, the reference sample was tasted by all assessors to remind the assessors about the correct use of the scale. In this serving, the reference was marked as a reference. In addition, the reference sample was served as blind sample during some of the sessions. Each assessor evaluated all samples 2 times and samples were served in randomized order. Samples were served with 5 min in between and a 10 min break through half the samples. Assessors used water and flat bread to clean the palate between samples. The evaluation was performed in separated booths under normal daylight and at ambient temperature according to ISO standard 8589. Data were collected on a computer system (FIZZ Network version 2.0, Biosystems, France).

Mechanical texture measurements

Mechanical texture measurements were performed with a texture analyser (TA-XT2, Stable Micro Systems, Surrey, England) equipped with a 5 kg load cell. The probe was a stainless steel cylinder (diameter: 11 mm) with approximately one-third of the cylinder base was rounded. Compression measurements were performed on the meat side of the raw fillets pieces. The rate was 1 mm/s. The force needed to compress the sample 40% of its height was recorded and the texture curves were recorded with an acquisition rate of 50 points per second. The max compression force was used as a measure of mechanical texture.

Analysis of pH, water, and lipid content

The pH measurements were performed directly in the minced samples by using an autocal pH meter (Metrohm, Denmark). Water content was measured by drying 2 g of the mince for 24 h at 105 °C. Afterwards, water content was calculated as the difference between the sample weight before and after drying. The lipid content was determined by extraction according to the method described by Bligh and Dyer (1959). Measurements of pH, water and lipid content were all performed in duplicate.

Table 2–Sensory descriptors used in the sensory profiling. The descriptors were evaluated on a 15 cm unstructured scale anchored 1.5 cm from each end.

Descriptor	Description	Scale Minimum (0 cm)	Scale Maximum (15 cm)
Odor			
Sweet	Sweet	None	Strong
Cooked potatoes	Cooked peeled potatoes	None	Strong
Wet dog	Wet dog	None	Strong
Sourish	Acidic, fresh citric acid	None	Strong
Warm milk	Warm milk but not boiling milk	None	Strong
Sickly sweet	As rotten fruit	None	Strong
Texture			
Firm	Force required to compress the sample between the molars	Soft	Firm
Juicy	The ability of the samples to hold water after 2 to 3 chews	Dry	Juicy
Oily	Amount of fat coating in the mouth surfaces	None	Strong
Flavor			
Sweet	Sweet, hot milk	None	Strong
Fresh fish oil	Fresh fish oil, green fresh hazelnut	None	Strong
Mushroom	Mushroom flavor	None	Strong
Sourish	Acidic, fresh citric acid	None	Strong
Cooked potatoes	Cooked peeled potatoes	None	Strong
Sour	Sour dishcloth, sour sock	None	Strong

Data analysis

The results from the sensory profiling were corrected for level effects by the method of Thybo and Martens (2000). After correcting for level effects, mean values for each assessor's replicates on each fish were calculated. These results and the weight (W), length (L), condition factor (condition factor $= 100 \times W/L^3$), QI, pH, water and lipid content were analyzed by using 1-way analysis of variance (ANOVA) and Tukey's post test to determined significant differences between individual fish in each group and between the 3 groups. For weight, length, and condition factor, only differences between the groups are analyzed.

In addition, principal component analysis (PCA) was used to study multivariate differences between sensory profiles of the individual fish in each group and between groups. Before this analysis, PCA was used to identify outliers between the evaluations of each fish. Outliers were identified as evaluations placed isolated in the score plot. All outliers were removed from the dataset. In total, 522 profiles were completed by the 11 assessors on the 30 fish, and 23 (4%) of these profiles were removed as outliers. Mean values for each assessor were calculated and used to calculate PCA models of each group. These mean values were furthermore used for calculating mean values for each of the 30 fish and these values were used in a PCA model used for studying differences between the groups. The optimal numbers of principal components (PCs) for all models were determined and score values for each of these PCs were used in an ANOVA and Tukey's post test to determine significant differences between individual fish in each group.

From the mechanical texture analysis, maximum compression force was used in a nonparametric Kruskal–Wallis test combined with Dunn's post test to determined significant differences in the texture of raw fillets.

Correction for level effects and PCA was performed using the Unscrambler 9.1 (CAMO, Trondheim, Norway). The statistical analysis was performed by using the program Prism (Version 4.2, GraphPad, San Diego, Calif., U.S.A.).

Results and Discussion

Comparison of individuals within the groups

In each of the 3 groups X, Y, and Z, significant difference was found for at least 2 of the sensory descriptors (Table 3 and Figure 1).

In group X, sample 6X had a rather special texture (Figure 1). In the sensory profiling, it had the firmest texture and the lowest intensity in juicy texture in group X (and also in group Y and Z). 6X was significantly different in firmness compared to 2 other fish (1X and 4X) from group X, and it was also less juicy than 0X and 1X. In the PCA analysis of results of the sensory profiling from group X both the first and second PC were significant (Table 5) and PC2 was related to the difference in texture. The loadings (Figure 2) show that high-score value in PC2 was correlated to firm texture and negative correlated to juicy texture. PC2 separated significantly ($P < 0.05$) 6X, which had high average scores from samples 0X, 1X, 4X, and 5X, which all had low average scores (not shown).

Table 3–Results from the ANOVA test (*P*-values) for each sensory descriptor in each group of samples.

	Group X	Group Y	Group Z
Odor			
Sweet	NS	0.0004	NS
Coked potatoes	NS	NS	NS
Wet dog	NS	NS	0.0407
Sourish	NS	NS	NS
Warm milk	NS	NS	NS
Sickly sweet	NS	NS	NS
Texture			
Firm	0.0062	0.0404	NS
Juicy	0.0059	NS	NS
Oily	NS	NS	NS
Flavor			
Sweet	NS	NS	NS
Fresh fish oil	NS	0.0201	NS
Mushroom	NS	NS	NS
Sourish	NS	NS	NS
Cooked potatoes	0.0431	NS	NS
Sour	NS	0.0036	0.0029

P-values higher than 0.05 were considered not significant (NS).

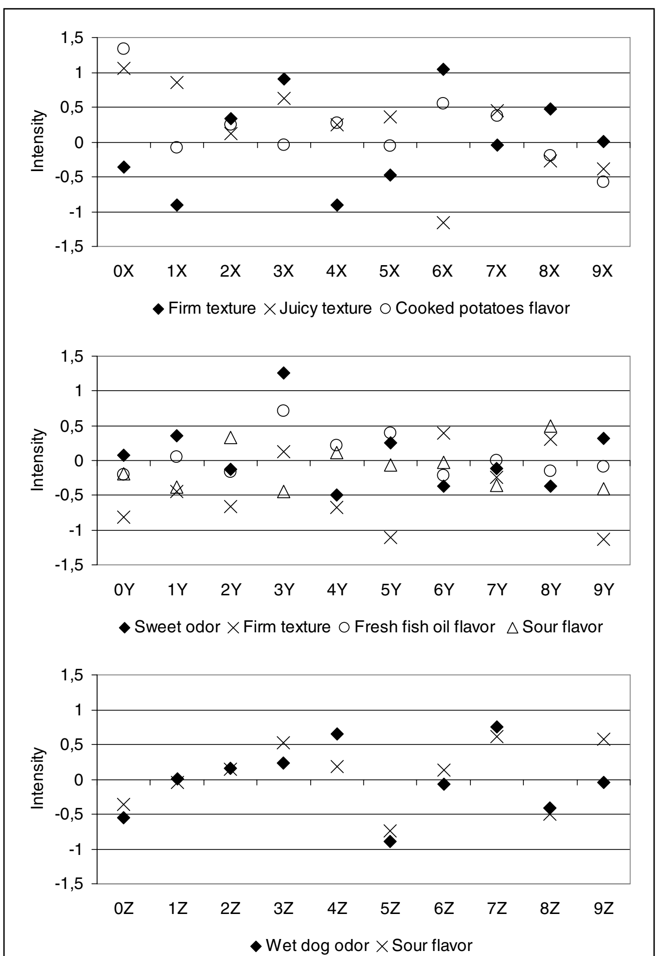

Figure 1–Level corrected results from the sensory profiling of significant sensory descriptors from each group (Table 3). Results from group X, Y, and Z are shown in part A, B, and C, respectively. The negative values arise because of the level correction and they do not indicate that the sensory characteristics do not exist in the fish.

Sample 6X was also special in the chemical composition since it was the fish in group X with the highest lipid content (12.0%) and the lowest water content (67.7%) (Table 4). In addition, each single sensory descriptor and the mechanical texture from each of the 30 fish were correlated to weight, length, condition factor, pH, water and lipid content. With one exception these correlations were not significant. The significant ($P = 0.006$) correlation ($r = -0.49$) was between sensory descriptor firm and lipid content, where low-lipid content was correlated to firm texture. This is in agreement with results from smoked (Einen and others 1999; Robb and others 2002) and cooked Atlantic salmon (*S. salar*) (Robb and others 2002), and form the results of Andersen and others (1997) on raw rainbow trout (*O. mykiss*). It is notable that no other significant correlations were obtained between the sensory descriptors and the mechanical texture and the chemical and physical characteristics, considering that there is considerable variation in, for example, lipid and water content.

However, there were not only differences in the sensory texture for group X but also in the sensory descriptor cooked potato flavor. Sample 0X and 9X had significantly different intensities of cooked potato flavor (Figure 1). 9X had the lowest lipid (7.6%) content and the lowest weight (3035 g) in group X. Furthermore, sample 9X was rather short (58 cm), while 0X was the longest (66 cm) and also one of the heaviest (3733 g) fish in group X. 0X also had higher lipid (10.0%) content than 9X (Table 4).

PC1 in the model for group X and group Y were both significant. These 2 PCs showed some similarities (Table 5), since both PCs divide the odor and flavor descriptors in 2 groups (Figure 2). One group includes sour flavor, wet dog, and sickly-sweet odor, while the other group includes the descriptors sweet, cooked potatoes, sourish and warm milk odor, and sweet, fresh fish oil, mushroom, sourish and cooked potatoes flavor. The Tukey's post test from group X of the PC1 scores did not significantly separate any of the fish. However, for group Y, sample 3Y had significant lower score values than 0Y, 2Y, 4Y, 5Y, 6Y, and 7Y ($P < 0.05$), which is correlated to the descriptors sweet, cooked potatoes, sourish and warm milk odor, and sweet, fresh fish oil, mushroom, sourish and cooked potatoes flavor. In the PCA model of group Y, the descriptor juicy is not included. The reason for this is that there were considerable variations in juicy in group Y, which was not related to the difference between fish, but related to differences in the scores between some of the assessors. If juicy is included in the PCA model for group Y, PC1 would primarily describe this variation in juicy (not shown).

When comparing the single-sensory descriptors, fish 3Y is different from many of the other fish in group Y (Figure 1). 3Y was sweeter than 0Y, 1Y, 6Y, 7Y, and 8Y. Furthermore, 2Y, 3Y, and 7Y had a lower intensity of sour flavor than 8Y. 3Y also had a high intensity of fresh fish oil than 6Y.

In group Z (Table 3 and Figure 1), some differences in the sensory profile were also found. These differences were related to the descriptors wet dog odor and sour flavor. 5Z had a low intensity compared to 6Z of wet dog. 5Z also had a low intensity of sour flavor compared to 3Z, 7Z, and 9Z. In the PCA analysis, no significant differences between the individual fish in group Z were found (Table 4). PC1 in the PCA model of group Z divides the sensory descriptors odor and flavor in a similar grouping as found for group X and Y (not shown).

Differences in mechanically measured texture between the individual fish were observed in both group X and Z. In group X, there were difference between 0X and 4X (Table 5). 4X had a remarkably lower maximum compression force, not only in group

X, but of all the fish in the study. In group Z, 2 fish (0Z and 2Z) had a significantly lower maximum compression force than 4Z (Table 4). 4Z had the highest maximum compression force and the lowest pH value of all the fish in the 3 groups. Furthermore, it was the fish with the highest lipid content (12.2%) in group Z. However, compared to the fish in group Y, 4Z did not have an especially high-lipid content.

No observed differences in QI was as expected found between the individual fish in the 3 groups (Table 4). 4Y, 8Y, and 8Z weighed less than 3000 g (2994 g, 2958 g, and 2980 g, respectively), which is low, since the fish were graded by weight (all fish were supposed to weigh between 3000 and 4000 g) before they were picked out for the study.

Comparison of groups

Table 6 shows a comparison of the 3 groups X, Y, and Z with regard to sensory profiling, QI, length, weight, condition factor, pH, lipid and water content, and the mechanical texture measurements.

The results from the sensory profiling showed variations between the groups. Five of the 15 sensory descriptors showed significant differences between 2 of the 3 groups. The significant descriptors included the odor descriptors sweet, cooked potatoes, and sickly sweet and the flavor descriptors mushroom and sweet. Groups X and Z were the most different since there were significant differences in all 5 significant descriptors. Group Y is significantly different from group X only in the descriptors cooked

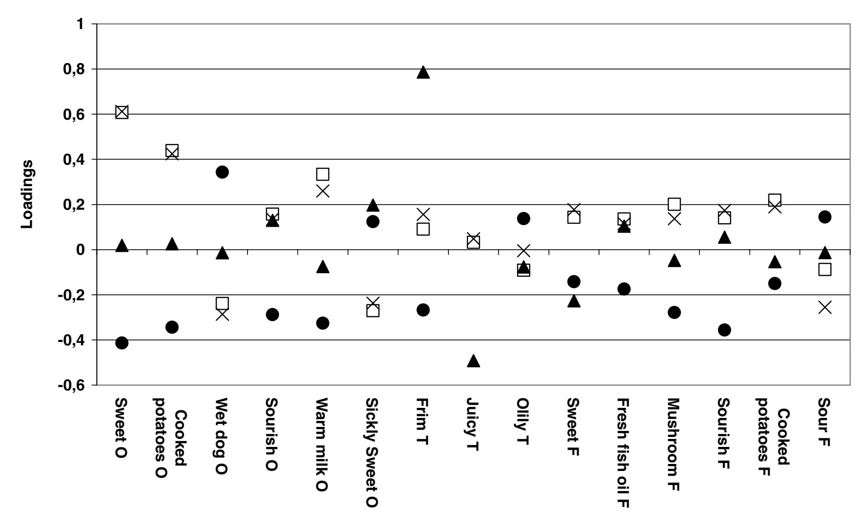

Figure 2–PCA loadings from the PCA models that had significant PCs (Table 5). The PCs are from the model of group X (PC1 □ and PC2 ▲), group Y (PC1 ●), and the comparison of the groups (PC1 ×).

Table 4–Average values of QI score from the QIM evaluations, length, weight, condition factor, pH, lipid content, water content, and maximum compression force from the mechanical texture measurement on each fish.

Group X	0X	1X	2X	3X	4X	5X	6X	7X	8X	9X	*P*-value[1]
QI	5.0	5.8	5.7	3.0	4.0	4.8	4.0	3.8	6.5	5.8	NS
Length (cm)	66	63	63	63	61	64	60	58	62	58	–
Weight (g)	3733	3229	3287	3463	3917	3840	3426	3116	3638	3035	–
Condition factor	1.30	1.29	1.31	1.38	1.73	1.46	1.59	1.60	1.53	1.56	–
pH	6.41^{c}	6.48^{a}	6.39^{c}	6.44^{b}	6.34^{d}	6.41^{c}	6.39^{c}	6.32^{d}	6.21^{e}	6.39^{c}	<0.0001
Lipid (%)	10.0^{bcd}	10.5^{b}	10.0^{bc}	8.0^{f}	8.6^{e}	9.1^{de}	12.0^{a}	9.1^{cde}	8.5^{ef}	7.6^{f}	<0.0001
Water (%)	70.7^{d}	71.2^{bcd}	69.7^{d}	72.1^{ab}	72.0^{abc}	70.7^{dc}	67.7^{e}	72.0^{abc}	70.3^{d}	72.8^{a}	<0.0001
Texture (g)	237^{a}	185^{ab}	178^{ab}	167^{ab}	73^{b}	196^{ab}	188^{ab}	201^{ab}	284^{ab}	126^{ab}	0.0106
	0Y	**1Y**	**2Y**	**3Y**	**4Y**	**5Y**	**6Y**	**7Y**	**8Y**	**9Y**	
QI	5.0	5.3	7.3	5.5	4.5	5.5	4.0	7.3	4.3	5.5	NS
Length (cm)	61	62	62	62	59	61	60	61	60	61	–
Weight (g)	3261	3500	3197	3333	2994	3283	3199	3030	2958	3327	–
Condition factor	1.44	1.47	1.34	1.40	1.46	1.45	1.48	1.33	1.37	1.47	–
pH	6.49^{a}	6.44^{cd}	6.41^{e}	6.43^{d}	6.40^{e}	6.49^{b}	6.39^{e}	6.44^{cd}	6.46^{c}	6.43^{d}	$P < 0.0001$
Lipid (%)	11.2^{abc}	11.4^{abc}	9.9^{bc}	12.6^{ab}	14.4^{a}	13.9^{ab}	10.1^{abc}	11.8^{abc}	7.9^{c}	10.6^{abc}	0.0052
Water (%)	69.6^{ab}	69.0^{ab}	71.2^{a}	69.4^{ab}	67.4^{b}	68.7^{ab}	69.2^{ab}	69.1^{ab}	71.2^{a}	69.0^{ab}	0.0048
Texture (g)	194	260	147	158	227	170	158	137	215	256	0.0018
	0Z	**1Z**	**2Z**	**3Z**	**4Z**	**5Z**	**6Z**	**7Z**	**8Z**	**9Z**	
QI	4.7	6.0	3.5	5.0	7.0	6.8	4.5	5.3	4.7	4.7	NS
Length (cm)	62	63	61	63	62	58	63	63	61	64	–
Weight (g)	3027	3444	3328	3008	3234	3068	3311	3440	2980	3455	–
Condition factor	1.27	1.38	1.47	1.20	1.36	1.57	1.32	1.38	1.31	1.32	–
pH	6.41^{b}	6.40^{b}	6.55^{a}	6.35^{d}	6.30^{e}	6.38^{c}	6.35^{d}	6.40^{b}	6.36^{cd}	6.36^{cd}	$P < 0.0001$
Lipid (%)	10.6^{bc}	7.3^{d}	10.9^{ab}	9.3^{c}	12.2^{a}	9.2^{c}	9.3^{c}	10.5^{bc}	9.3^{c}	9.9^{bc}	$P < 0.0001$
Water (%)	70.0	71.3	71.0	69.2	68.9	70.6	70.3	71.2	71.5	70.0	NS
Texture (g)	195^{b}	248^{ab}	176^{b}	231^{ab}	439^{a}	313^{ab}	255^{ab}	269^{ab}	375^{ab}	243^{ab}	0.0039

Superscript letters show which fish are significantly different from each other for each variable based on Tukey's posttest.
[1] *P*-values higher than 0.05 were considered not significant (NS).

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potatoes and sickly-sweet odor. Furthermore, group Y is significantly different from group Z in the descriptors mushroom and sweet flavor. The analysis of the PCA scores showed a significant ($P < 0.05$) difference between group X and Z in the first PC (Table 5), group X having a higher mean score value than Z. A high PC1 score is generally related to the descriptors sweet, cooked potatoes and warm milk odor, and sweet, fresh fish oil, mushroom, sourish and cooked potatoes flavor. This division of the descriptors is similar to the division found in PC1 in the models of the fish in group X and Y (Figure 2).

Table 5–Results from 4 PCA models (1 for each of the 3 groups and 1 where all groups are compared) of the results from the sensory profiling. The table includes optimal number of principal components (PCs) and explained variance of the PCs and *P*-values.

	Group X[a]	Group Y[a,b]	Group Z[a]	Group differences[c]
Optimal number of PCs	2	1	1	2
Explained variation				
PC1	22%	19%	23%	38%
PC2	15%	–	–	21%
P-value[d]				
PC1	0.0371	0.0055	NS	0.0251
PC2	0.0002	–	–	NS

[a]In the PCA models average values for each assessor on each fish were used.
[b]In the model, the descriptor juicy was left out.
[c]In the PCA model, average values for each fish of all assessors were used.
[d]*P*-values higher than 0.05 were considered not significant (NS).

Table 6– Comparison of group X, Y, and Z. Average values, standard deviations, and *P*-values from the sensory profiling (level corrected values), QI score from the QIM evaluations, length, weight, condition factor, pH, lipid content, water content, and max compression force from the mechanical texture measurement.

	Group X	Group Y	Group Z	*P*-value[1]
Sensory profiling[2]				
Odor				
Sweet	0.50 ± 0.58[a]	0.06 ± 0.52[ab]	−0.42 ± 0.42[b]	0.0018
Cooked potatoes	0.44 ± 0.38[a]	−0.05 ± 0.25[b]	−0.27 ± 0.38[b]	0.0003
Wet dog	−0.07 ± 0.34	0.12 ± 0.31	−0.02 ± 0.51	NS
Sourish	0.10 ± 0.19	−0.01 ± 0.23	−0.04 ± 0.14	NS
Warm milk	0.19 ± 0.36	−0.05 ± 0.26	−0.10 ± 0.29	NS
Sickly sweet	−0.40 ± 0.22[b]	−0.03 ± 0.16[a]	0.23 ± 0.37[a]	$P < 0.0001$
Texture				
Firm	0.03 ± 0.68	−0.32 ± 0.50	−0.07 ± 0.39	NS
Juicy	0.19 ± 0.64	0.23 ± 0.36	−0.20 ± 0.28	NS
Oily	−0.03 ± 0.19	0.08 ± 0.36	−0.11 ± 0.19	NS
Flavor				
Sweet	0.15 ± 0.33[a]	0.20 ± 0.22[a]	−0.21 ± 0.22[b]	0.0030
Fresh fish oil	0.12 ± 0.22	0.06 ± 0.30	−0.01 ± 0.30	NS
Mushroom	0.27 ± 0.25[a]	0.05 ± 0.22[a]	−0.26 ± 0.22[b]	$P < 0.0001$
Sourish	0.22 ± 0.20	0.01 ± 0.37	−0.05 ± 0.33	NS
Cooked potatoes	0.16 ± 0.49	−0.17 ± 0.15	0.05 ± 0.32	NS
Sour	−0.07 ± 0.30	−0.09 ± 0.33	0.05 ± 0.46	NS
QI	4.8 ± 4.0	5.4 ± 4.6	5.2 ± 4.2	NS
Length (cm)	62 ± 3	61 ± 1	62 ± 2	NS
Weight (g)	3468 ± 306[a]	3208 ± 171[b]	3330 ± 193[ab]	0.0323
Condition factor	1.47 ± 0.15	1.42 ± 0.05	1.36 ± 0.10	NS
pH	6.38 ± 0.08	6.44 ± 0.03	6.39 ± 0.06	NS
Lipid (%)	9.3 ± 1.3[b]	11.5 ± 1.9[a]	9.9 ± 1.3[ab]	0.0123
Water (%)	70.9 ± 1.5[a]	69.4 ± 1.1[b]	70.4 ± 0.9[ab]	0.0215
Texture (g)	183 ± 57[b]	192 ± 45[b]	274 ± 81[a]	0.0147

Superscript letters show which fish are significantly different from each other for each variable based on Tukey's posttest.
[1]*P*-values higher than 0.05 were considered not significant (NS).
[2]The negative values arise because of the level correction and they do not indicate that the sensory characteristics do not exist in the fish.

The chemical and physical measurements did not give any explanation for the considerable difference between group X and Z (Table 6), although the 2 groups differed in the mechanical texture measurement, where group Z had a higher maximum compression force on the raw fillet than group X. Groups X and Y are however, most different when comparing the chemical and physical measurements. The fish in group X generally have a heavier weight (3468 g compared to 3208 g), higher water content (70.9% compared to 69.4%), and lower lipid content (9.3% compared to 11.5%) than the fish in group Y. As expected, no observed difference in QI was found between the 3 groups. The difference in sensory, chemical, and physical characteristics between the groups shows that the characteristics of the batch of Rainbow trout were inconsistent during the production day. This inconsistency is most likely caused by biological variation.

Conclusion

The results confirm the hypothesis that there can be significant differences in sensory profiles of heat-treated individual Rainbow trout belonging to the same production batch. In addition, the results show that there are differences in sensory profiles between groups of Rainbow trout collected at different times during a production day. In addition, differences in mechanically measured texture between individuals and groups of fish from the same production batch were shown.

Negative correlations between firm sensory texture and a high-lipid content was observed. However, generally the results from the chemical and physical measurements gave no explanation of the differences in the sensory profiling or the mechanical texture measurements. Differences in pH, lipid content, and water content were observed between several of the individual fish. Similar significant differences between weight, lipid content, and water content were observed between groups of fish.

The differences in sensory profile of individual fish from a single production must be taken under critical consideration when performing scientific studies in the future. In both scientific studies and in an industrial production, the variations will increase the number of samples necessary for a valid conclusion.

A special problem arises when performing sensory evaluations on smaller fish where not all assessors can evaluate samples from the same fish. In that case, assessors are normally given samples from the same production batch. This study shows that the difference from fish to fish can be so significant that the sensory assessors will disagree in their evaluations. This is a problem both in relation to training of the assessors and in the data analysis. In order to ensure that valid conclusions can be obtained in future experiments, it is recommended to critically consider the number of replicates that should be used. If at all possible especially during training but also in the experiment assessors should get samples from the same fish. In experiments where the fish size does not permit that all assessors taste the same fish, it could perhaps be an advantage during training to reduce the sample size, thereby allowing more assessors to taste the same fish. In such a case, one would only train a few sensory descriptors on each sample.

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Paper IV

A model for communication of sensory quality in the seafood processing chain

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A MODEL FOR COMMUNICATION OF SENSORY QUALITY IN THE SEAFOOD PROCESSING CHAIN

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ABSTRACT

Sensory quality has a key influence of consumer perception of a product. It is therefore of great importance for the processing industry that the sensory quality fulfils the expectations of the consumer. Sensory evaluations are the ultimate tool to measure and communicate sensory quality, but it is generally not fully implemented in the chain from catch to consumer. The importance of communicating sensory demands and results from evaluations in the seafood processing chain is described and a Seafood Sensory Quality Model (SSQM) is suggested as a communication tool.

KEYWORDS

Seafood, Sensory, Quality, Model, Fish, Processing,

INTRODUCTION

Quality is a multidimensional and complex concept since many different parameters have effects on product quality (Bremner, 2000).

Quality of food can be defined as the degree to which a product meets certain needs under specified conditions. The definition depends on the particular context where it is applied, and with differences in the concept of quality confusion can arise mostly due to the combined qualitative and quantitative dimension of quality (Grunert, 2005). Consumer perception of food is in its nature subjective, but in the communication in the food chain between researchers, industry and retailers a common view of an objective definition is necessary. The correlation and translation between the subjective and the objective understanding of quality is at the core of the economical importance in the production chain (Grunert, 2005). The product is competitive only when the producers have an understanding of the consumer perception.

Many factors have influence on the perception of food quality as described in the Total Food Quality Model, introduced by Grunert et al. (1996). The model includes the importance of health, convenience and processing but also the importance of sensory quality is emphasized. However, managing sensory quality of food products is complex, since the sensory quality is affected by various factors. In the following fish is used as a food model (Figure 1). In relation to fish some factors are connected to the living fish, as example genetics, age, seasons and growing conditions. On top of that catching methods, handling after catch, method of slaughtering, processing, storage and transport are important

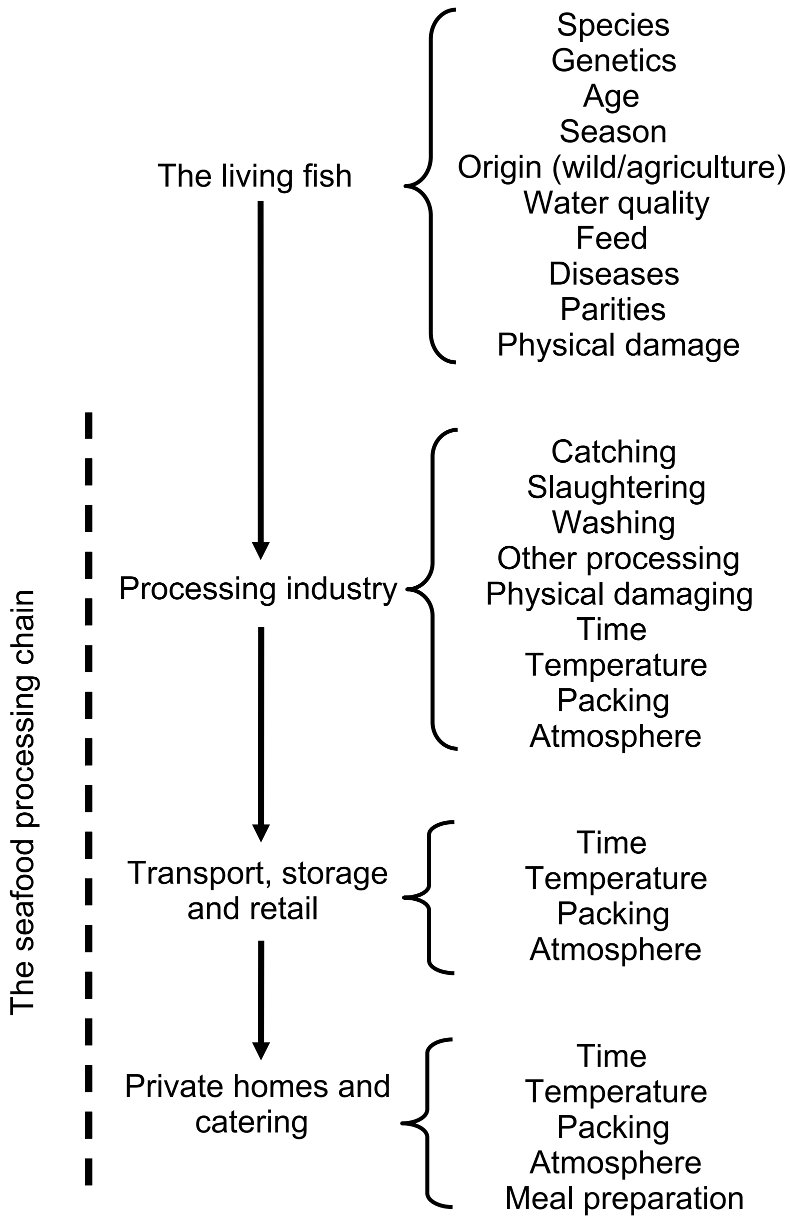

Figure 1. Overview of different factors, which can affect the sensory quality in the fish processing chain.

The steps from catching/slaughtering until consumption is throughout this paper referred to as the seafood processing chain. In all the steps in the chain, time and temperature is very important for the sensory quality. Because time and temperature correlate to the loss of freshness, which is of major importance for the sensory quality

(Nielsen et al., 1997; Olafsdottir et al., 1997; Peary et al., 1994). The different steps take place in as different locations as fishing vessels, aquaculture ponds and pens, slaughterhouses, different means of transport, processing industry, fishmongers, supermarkets, catering businesses and consumers' homes (Hyldig et al. 2007; Hyldig 2007). All these steps might have a different concept of sensory quality. The importance of a good management practice of sensory quality increases with increasing number of steps and partners in the seafood processing chain.

Sensory analyses are already used in many of the steps in the chain. The partners in the chain generally believe that they deliver a quality, which satisfies the next partner in the chain; but the terms of sensory quality are seldom used in a systematic way. Additionally, the results from the evaluations is normally not recorded or shared between the different steps. Furthermore, most of the participants only have little knowledge about the sensory quality demands of the consumers (Martinsdóttir et al., 2008).

This paper outlines how sensory analysis can be used in the seafood processing chain, and suggests a Seafood Sensory Quality Model (SSQM) to be used for communication between the partners in the chain. The vision of SSQM is as a general tool that can be used to manage quality in the total chain.

SENSORY EVALUATIONS IN THE SEAFOOD PROCESSING CHAIN

To understand the SSQM it is necessary to understand which sensory methods is relevant to be used in the seafood processing chain; and to go into details of where and how the methods can be used in the different steps in the chain. The choice of method depends on a number of different factors including the reason of performing the sensory evaluations. An overview of important factors of relevance for the sensory evaluations in the seafood processing chain can be seen in Table 1. The table includes references to Figure 2 which shows an example for a typical seafood processing chain, including suggestions for where it can be relevant to perform sensory evaluations (test points).

The value of the SSQM is depending on the reliability of the sensory evaluation performed in each step of the seafood processing chain. Demands to sensory quality needs to be defined, the most appropriate methods must be used in evaluations and sensory evaluations should be performed according to standards as e.g. the guidelines for sensory test (NMKL Procedure No 21, 2008; ISO standards 8586-1, 1993; ISO standards 8589, 1988).

TABLE 1. Important factors relevant to measure in the seafood porcessing chain.

Purpose	**Test point from Figure 2**[1]
Freshness	3, 4, 7, 9 and 10
Species	1,3 and 4
Physical damage of the fish	1, 3 and 4
Fish illness	1, 3 and 4
Presence of foreign matter	2, 3, 4, 6, 7, 9 and 10
Presence of parasites	5, 6 and 7
Presence of bones	6, 7, 9 and 10
Amount of ice	2, 3 and 4
Quality of bleeding	2, 3 and 4
Quality of gutting	2, 3 and 4
Quality of washing	2, 3 and 4
Quality of parking	4, 6, 7, 9 and 10
Quality of filleting	6 and 7
Presence of gaping	5, 6 and 7
Colour and homogeneous	5, 6, 7, 9 and 10
General appearance	7, 9 and 10
Presence of off-odours	7, 9 and 10
General odour	7, 9 and 10
Texture	4, 7, 9 and 10
Taste	7, 9 and 10
Quality of other ingredients	8

[1]Shows references to were the different sensory test purposes can be relevant in the example of a seafood processing chain from Figure 2.

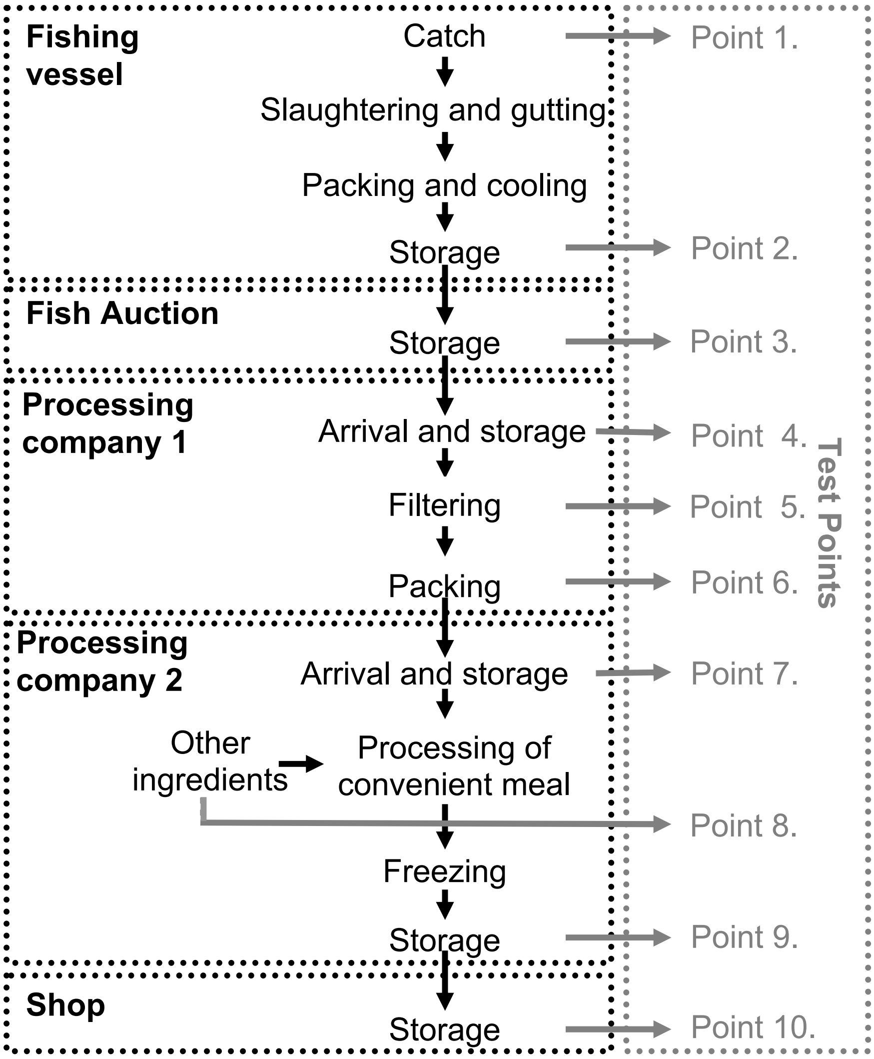

Figure 2. Example of a realistic seafood processing chain. The example includes suggestions of sensory quality test points. Steps of transport between the different companies in the processing chain is not shown.

The sensory evaluations can be performed as visual inspection, measurement of odour, texture and taste. Visual inspection can be performed on whole fish and raw or heat treated fillets. Chance in freshness influence the appearance of fish and visual inspection can therefore be part of freshness evaluation. Visual inspection can also be used to detect other characteristics as fish species, physical damage and the presence of some diseases in the fish. Physical damage can cause a fast reduction in shelf-life. Furthermore, it can influence the appearance of the final product (Hyldig et al., 2007). Another purpose of visual inspection can be to check the product for foreign matter not wanted in the product. This can be e.g. sand, seaweed, packing material, bones or parasites. Also, the quality of washing, packing, gutting, bleeding and filleting as well as the amount of ice packed with fish can be inspected with visual tests. Additionally, flesh colour, gaping and homogeneity of the flesh can be tested with visual inspection of both raw and cooked fish. In total there are many different objects of visual testing that is relevant for inspection in the seafood processing chain. Visual inspection can be relevant to perform in all the showed test points in relation to Figure 2.

Another type of sensory assessment is evaluation of odour, which again can be performed on both raw and heat treated samples, while evaluation of taste is done on heat treated products or products preserved in another way as e.g. sushi and marinated fish. In the seafood industry, sensory tests of the taste are normally performed on a company's final product (Martinsdóttir et al., 2008). Odour and taste evaluation of seafood can be made as part of a freshness evaluation, for instance by cheeking for the presence of rancid odour and flavour. Odour and taste evaluations can also be performed to check off-odours e.g. muddy or earthy odours (Howgate, 2004) or spices in manufactured products.

Texture can also be measured on both raw and cooked samples, and texture evaluations can be part of a freshness evaluation since for example, firmness of the fish flesh is reduced during storage in ice (Sveinsdottir et. al, 2002). Other aspects of texture which can be of interest are juiciness and tough of cooked fillets.

Different sensory methods can, be used in the sensory evaluations. It is important that the methods used have sufficient precision in measuring a given characteristic (Costell, 2002). Additionally, the methods usually need to be fast both to perform and in the subsequent data analysis. The most suitable methods are generally descriptive tests and quality ratings, which make it possible to measure the degree of the variation between the product and the demands to sensory quality. In some cases in/out methods can be recommended (Munoz et al., 1992).

In descriptive tests the intensity of a single sensory parameter is evaluated on a scale (Lawless and Heymann, 1998). The result from the descriptive tests needs to be translated into different quality levels. The main advantages of using descriptive tests in a production chain are that the result gives a complete picture of the characteristics and their intensity. The disadvantages of descriptive tests are that they are relatively time demanding in training of the assessors and in data treatment (Munoz et al., 1992).

In quality rating, characteristics are also evaluated on scales. However, these scales are quality scales with end points such as "very poor quality" and "excellent quality". Quality rating has some disadvantages compared to descriptive tests as descriptive tested gives the intensity of every single attribute. This means that more detailed data can be establish from descriptive tests. Additionally, quality rating demands also a longer training program for the assessors compared to descriptive test (Munoz et al., 1992), since it is important that the assessors understand the different quality levels.

Descriptive test and quality rating can both be used for many different purposes in relation to the seafood processing chain. This includes determination of freshness, appearance (including colour and homogeneity), odour (including off-odours), taste and texture (Table 1). Descriptive test and quality rating are therefore relevant methods in most of the test point shown in Figure 2 (test point 2 to 4 and 6 to 10).

In in/out methods the assessors decide whether the product is within or outside a given standard. Assessors need also here to be trained in using the standards; however, the training is not as extensive as for descriptive methods. Another advantage is that the results are known instantly. In/out methods can be used if a simple classification of the samples is satisfactory (Munoz et al., 1992). In/out method are especially relevant in relation to on-line evaluations (test points 1 and 5 in Figure 2). For instance in/out methods can be used in evaluation of appearance, physical damage, fish diseases, unwanted substances, parasites, bones, amount of ice in the box, gaping, and quality of gutting, washing, packing and filleting.

Measurement of fish freshness is as described important in the seafood processing chain. In the example from Figure 2 it is relevant to measure freshness in test point 3, 4, 7, 9 and 10. Specific sensory methods including The EU scheme (Anonymous, 1996), Quality Index Method (QIM) (Bremner,1985; Hyldig and Green-Petersen 2004) and the Torry scale (Howgate et al., 1992) have been developed for evaluation of freshness of fish.

COMMUNICATION IN THE SEAFOOD PROCESSING CHAIN

An overall problem in the seafood processing is that results from the sensory evaluations in a single step of the chain, most often is unavailable to the other partners in the chain. This is a setback since the results generally are relevant not only for the partner performing the evaluations, but also for the other partners. Examples demonstrating the value of sharing sensory quality information in the seafood processing chain are shown in the following.

Example 1: A company producing fish fillets

Processing company one from Figure 2 buy raw material (fish) from a fish auction and store the fish until filleting and packing - the packed filets being the end product. The company measure freshness by using the sensory evaluations of the raw material (test point 4 in Figure 2). The company can use the measured freshness first of all to decide if the freshness is acceptable and therefore the use of the raw material in the production. Furthermore the results can be used to determine how long the fish can be stored before production and also to establish the self-life of the companies final product. The measured freshness gives additionally the company documentation for the fish quality, which can be used in relation to the other partners in the chain.

For the partners earlier in the chain, the fishing vessel and the auction (Figure 2), the results are of high relevance because they contain information about the quality of the product from the fishing vessel and the auction, and the information can be used for optimizing the handling of the fish. Furthermore processing company one can use the results to determine what they are willing to pay for the raw material.

The partners later in the chain can also benefit from the information of the results from the sensory freshness evaluation performed in test point 4, since freshness here has significant influence on freshness later in the chain. First of all the product must have a freshness which will satisfy processing company two for their production. Secondly processing company two might use the freshness evaluation results from test point 4 to

predict the shelf-life of their own products. Additionally if processing company two have the results from test point 4, they might be able to reduce the extent of sensory testing performed on their raw material and/or final product (point 7 and 9) – again this demand that a systematic model for sharing of information is used.
Sharing of information in the chain requires, however, an accepted communication tool.

As illustrated in the example communication of sensory quality is an advantage both for the partner performing the sensory testing and for partners earlier and later in the processing chain. Moreover communication of sensory quality can be used for optimizing the production in the different steps of the chain. Communication is also valuable in relation to determination of the optimal way of performing sensory evaluations. First of all as illustrated in the example above, communication can reduce the amount of sensory evaluations to be performed. Secondly communication and relation of quality between the different test points can be used for evaluation of the relevant measurements. According to Munoz et al. (1992) there are two major factors that determine which sensory characteristics should be evaluated, 1) the sensory characteristics must show a variation, 2) the sensory characteristics must affects consumer attitude towards the product.
The following example shows how communication and relation of sensory quality between different test points can be used to determine which sensory characteristics should be measured in the different test points.

Example 2: A company producing frozen convenient meals
Processing company two from the seafood processing chain in Figure 2, are buying packed filets from processing company one to produce frozen convenient meals. Processing company two might have a considerable variation in the sensory quality of the raw material (measure in test point 7). The quality can e.g. vary according to filleting quality and colour. In order to determined what sensory characterises is going to be measured in test point 7, company two needs first to investigate the relationship between the quality in test point 7 and 9 by making descriptive sensory measurements at both points. If the results show that e.g. both the quality of filleting and colour in point 7 has influence on the appearance of the product in point 9, the company needs to find out

how this variation affects the consumers. This should preferable be done by performing consumer test, which includes samples representing the different appearances caused by the variation in the quality of filleting and colour. If the consumer test show that filleting has a considerable influence on consumer acceptability, while the variation in colour has no effect, it is clear that it would be beneficial for processing company two to define quality demands of the filleting in test point 7 and perform sensory tests here. Furthermore processing company two should inform processing company one about the demands to filleting quality and the results from the evaluations performed in test point 7.

The results from the consumer test, regarding the non-existing influence of colour on the consumer acceptability of the products, does not necessarily implicate anything about the relevance of defining sensory standards and measurement of colour in test point 7. This is due to the fact that the variation in colour might influence the consumers confidence and thereby the reliability of the product (Stone and Sidel, 1993).

Again the sharing of information in the chain requires an accepted communication tool.

THE SEAFOOD SENSORY QUALITY MODEL (SSQM)

To establish communication of sensory quality in the seafood processing chain the SSQM (Figure 3) is suggested. The SSQM can be used to communicate the sensory quality of seafood, and make it possible to share the understanding of the sensory quality. The SSQM makes it achievable to document sensory quality in different test points and to relate it to every step in the chain. Not only results from sensory evaluation, but also other information with an effect on the sensory quality can be included. Additionally the SSQM is valuable in relation to deciding which sensory characteristics should be measured in the different test point in relation to product decision and product development.

Figure 3 illustrates the SSQM with the different steps from vessel/aquaculture to consumer and show the information flow used for the communication within the processing chain and the surrounding companies. The SSQM can be used for communicating demands and results from sensory evaluations and for communicating other characteristics which can influence the sensory quality as microbiological, physical and biochemical characteristics (e.g. Refsgaard et al., 1998; Sveinsdottir et al., 2003, Robb et al., 2002) together with time and temperature information.

The SSQM should as far as possible be easy to use. It implies that the sensory quality information after being registered automatically must be passed on to the relevant partners in the chain. Using the internet for this information flow is an obvious possibility. The system could function in parallel with systems used for traceability.

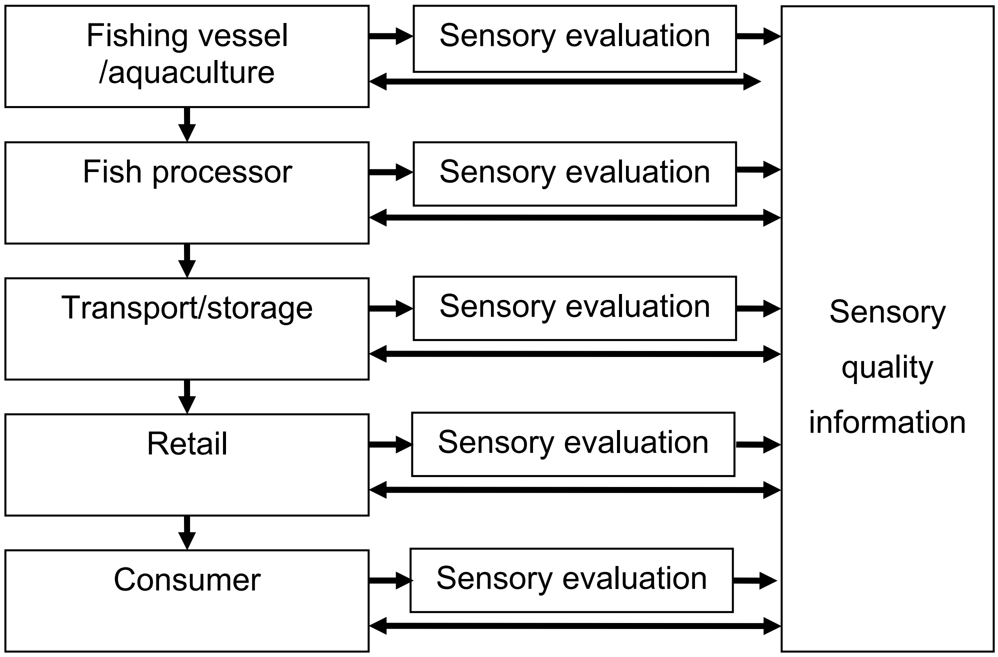

Figure 3. Illustration of the Seafood Sensory Quality Model (SSQM).

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